U.S. Fish & Wildlife Service

Maryland Stream Survey:

Bankfull Discharge and Channel Characteristics of Streams in the Piedmont Hydrologic Region

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MARYLAND STREAM SURVEY: BANKFULL DISCHARGE AND CHANNEL CHARACTERISTICS OF STREAMS IN THE PIEDMONT HYDROLOGIC REGION

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Prepared in cooperation with:

Maryland State Highway Administration and

U.S. Geological Survey

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Executive Summary

Increasingly, engineers and environmental managers are attempting to design in accordance with the natural tendencies of rivers in flood protection, channel stabilization, stream crossing, channel realignment, and watershed management projects. There is also a great interest in restoring the physical, biological, and aesthetic characteristics of previously degraded rivers. For both these endeavors, designers need basic information to evaluate and predict the dimension, pattern, and profile of natural rivers.

Empirical relationships between dimensions of bankfull channel geometry (i. e., width, depth, cross-sectional area) and water discharge or drainage area have long been found useful as a first step towards preliminary design and evaluation of river channels. An increasing number of river design approaches require or recommend the use of such relationships. As with all empirical relationships, the applicability of the derived predictive equations is limited to rivers similar to those providing the data. Thus, empirical relationships for channel geometry are for specific hydro-physiographic regions with relatively homogeneous climate, geology, and vegetation.

The U.S. Department of Interior, Fish and Wildlife Service (Service) and the Maryland State Highway Administration (SHA) in conjunction with the U.S. Geological Survey (USGS) are developing regional channel geometry relationships for major hydro-physiographic regions in Maryland. The first phase of the survey involves detailed channel geometry surveys at stream gages operated by the USGS in the Piedmont hydro-physiographic region of Maryland. Later phases of the survey will address the Coastal Plain (eastern and western), Ridge and Valley, and Appalachian Plateau provinces. Channel surveys and gage flow records are used to establish discharge magnitudes, recurrence intervals, cross-section, channel pattern, and longitudinal profile dimensions corresponding to the bankfull stage. Preliminary data reveal significant relationships between drainage area and bankfull channel dimensions and discharge.

The Service and SHA have obtained the cooperation of the state and federal agencies involved in the review of highway projects through the formal Partnering Agreement and formation of a Maryland Stream Survey Advisory Panel. It is important that all interested agencies agree to the approach and objectives of the survey. The agencies agreed that, upon review and acceptance by the Advisory Panel, the information would provide a useful tool for evaluating the effects of proposed projects in channel, wetlands, and flood plains.

OBJECTIVES
The Service and SHA developed objectives agreeable to all parties. These objectives include:
- determine and analyze the hydraulic and planform characteristics of Maryland streams,
- determine the degree to which the Rosgen Classification System can explain and account for the amount of variability in the data, and
- develop regional channel geometry relationships to facilitate and improve the accuracy of future studies that evaluate and classify stream channels.

EXPECTED RESULTS AND PRODUCTS
A database of stream characteristics will serve as a source of information on basic channel characteristics at the time of the surveys, for anyone involved with work affecting Maryland

streams. The analyses from the stream surveys will provide regional channel geometry relationships useful for watershed management, emergency watershed protection, and other stream restoration and protection efforts.

For the first phase of the project, the Service will produce a document incorporating the following:
1) *Maryland Stream Survey: Bankfull discharge and channel characteristics of streams in the Piedmont hydrologic region;*
2) *Appendix A: Site characteristics for selected USGS gage stations in the Piedmont hydrologic region;* and
3) *Appendix B: Protocols for field surveys at gage stations.*

Phase II will result in additional reports on the sites characteristics of streams in the Appalachian, Ridge and Valley, and Coastal Plain hydro-physiographic provinces along with the examination of relationships of bankfull discharge and drainage area and channel dimensions and drainage area.

PHASE I – PIEDMONT HYDRO-PHYSIOGRAPHIC REGION

In this Pilot Study, we conducted surveys of 25 gaged stream reaches in the Piedmont hydro-physiographic province of Maryland to test for relationships between:
a) drainage area and bankfull discharge;
b) drainage area and bankfull channel dimensions;
c) planform and riffle-pool attributes;
d) bankfull discharge and channel cross-section dimensions; and
e) relative roughness and flow resistance.
We also classified each reach according to the Rosgen classification system of natural rivers (Rosgen, 1994, 1996a), and examined the utility of such classification for explaining the observed variability in the above relationships.

Because of concerns raised by the Advisory Panel regarding the issue of whether the gage survey sites represented reference reaches, the information related to channel size and planform, riffle-pool attributes, and other discussions on channel geometry have been deleted from the report.

FINDINGS

Bankfull Discharge

Bankfull discharge is significantly related to drainage area, with about 93% of the variability in discharge explained by drainage area (Figure 1). Examination of Figure 1 reveals that the data for four locations located in the northeastern Piedmont region plot relatively high.
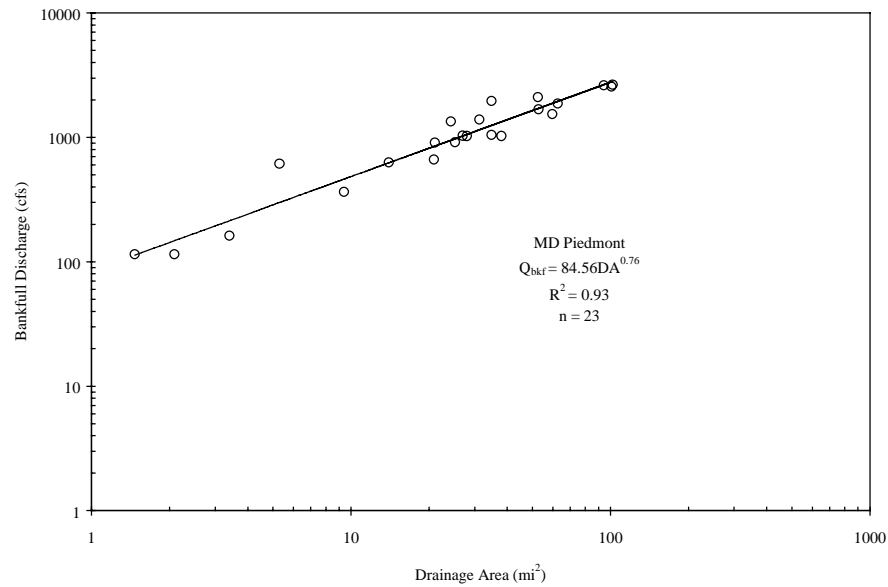
Figure 1. Bankfull discharge as a function of drainage area for Maryland Piedmont survey sites.

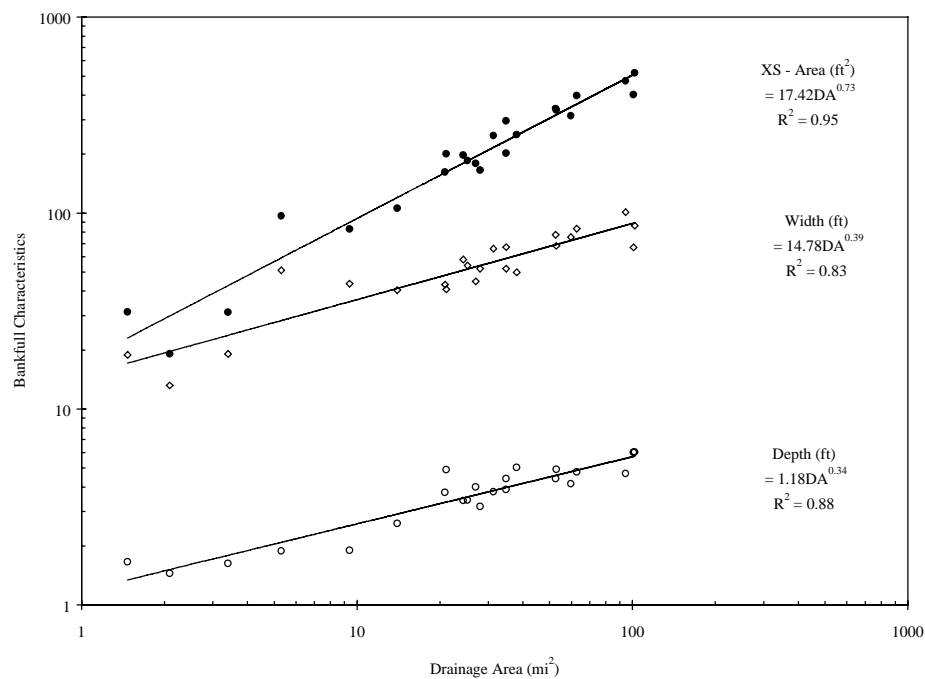*Figure 2. Bankfull channel dimensions as a function of drainage area for Maryland Piedmont survey sites.*

Bankfull Indicators

Physical features of streams indicate certain discharge events, mostly notably the bankfull discharge. Bankfull indicators include geomorphic features developed by the channel as well as distribution limits for vegetation. We found several indicators of bankfull stage in the Piedmont

streams, and observed that the floodplain break was the dominant indicator associated with the bankfull discharge.

Bankfull Discharge Recurrence Interval
The recurrence intervals for the bankfull discharge associated with the dominant indicators range from 1.26 – 1.75 years, and average 1.5 years.

Cross-section Relationships by Drainage Area
Width, mean depth, and cross-sectional area are all significantly related to drainage area and bankfull discharge (Figure 2). Of the three parameters, cross-sectional area has the greatest percent of the variability in size explained by drainage area, followed by depth and width, as indicated by the regression coefficients of determination (R^2).

Resistance Relationships
There is a negative but significant relationship between relative roughness (R/D_{84}), and resistance expressed as Manning's "n".

Rosgen Classification
In that all the reaches we surveyed classified to a specific stream type, the results of this study support the applicability of the Rosgen classification system to Piedmont channels. However, a limited number of stream types were observed at the gage stations in the Piedmont – most of the channels classified as C type streams, and of these C4 (gravel) – type channels were predominant.

CONCLUSIONS
- The relationships presented here serve to provide preliminary design parameters for streams with a similar range of characteristics. The results of this work should guide practitioners in the expected bankfull channel dimensions at ungaged streams.

- Maryland Piedmont channels can be classified using the Rosgen stream classification system, however the limited number of independent observations of different stream types at this point in the work prevents us from examining the use of the classification in helping explain some of the observed variability in stream characteristics.

- The northeastern Piedmont may constitute a discrete region with respect to the relationship between drainage area and bankfull discharge. However, more surveys are necessary for a proper statistical analysis.

- There is a well-defined relationship between drainage area and bankfull discharge in the main Piedmont region.

- There are well-defined relationships for Maryland Piedmont streams between drainage area and bankfull channel dimensions, and these relationships compare favorably to those documented by previous workers elsewhere in the Piedmont of the eastern U.S. and nearby regions. The most conservative relationship with drainage area is for cross-sectional area.

- Variability in the average flow resistance in Maryland Piedmont streams as represented by the Manning "n" is fairly well explained by variability in relative roughness, expressed as R/D_{84}.

APPLICATIONS
Use of Regression Relationships for Design Purposes

Several caveats exist for these relationships, and argue strongly against their use for detailed design specifications.

- Relationships are representative of a restricted range of basin and reach characteristics (e.g. drainage area, geology, land use, etc.) and must be used with caution when applying to streams across the Piedmont.

- Often the gage and study reaches are not the same reaches. Rather to maintain the study reach selection parameters, it is often located upstream of the gage.

- While we do not consider any of the reaches represented here to be in a state of rapid adjustment, we have no information about the relative rates of lateral or down-valley meander migration.

- Relationships are not necessarily representative of "reference reach conditions". We suspect that many reaches in proximity to gages at road crossings were altered at some time in the past by channelization or realignment. These relationships provide no information about ecological parameters, and may not represent "good" habitat conditions. In fact, the low amounts of large woody debris in the surveyed channels are likely an indication of relatively poor habitat conditions.

- The range of stream types represented by the data is low, consisting of one to three in most stream types, with only C4 stream types well represented.

- The reaches represented here seem to broadly correspond to the category termed "transport" reaches, in that there are not many well-developed depositional features such as point bars. Imposition of the channel characteristics represented by these relationships on streams in the "source" and "response" categories would likely be problematic.

Given these caveats, the relationships documented here can provide preliminary design parameters for streams with a similar range of drainage area, sediment, slope, and entrenchment conditions. Channel designers need to identify discrete project goals and objectives, with respect to both physical and biological desired conditions, and determine the appropriate design parameters for achieving those conditions. In most cases the best design guidance for finer scale aspects of channel design will come from carefully selected reference reaches that closely match the controlling conditions at the project reach, and exhibit those characteristics specifically identified as design objectives. The results of this study may best serve as guidance to the expected range of bankfull channel dimensions at ungaged reaches.

RECOMMENDATIONS FOR ADDITIONAL WORK

- Once the gage calibration surveys represented by Phases I and II are in-hand, the information can be used to facilitate identification of bankfull channels at ungaged reference reaches selected for particular purposes including biological quality, sediment transport, over-bank discharge frequency, and diversity of fluvial features. This information will provide a foundation for future development of a reference reach design database for Maryland streams.

- Additional sites should be surveyed in the northeastern Piedmont. Although additional active gage sites are not available, discontinued stations with updated stage-discharge relationships would provide useful information regarding the magnitudes of bankfull discharge and channel dimensions.

- Additional observations of stream reaches, and reaches with less bedrock control and perhaps a greater range of bank material composition than was present in this set of study sites, will be necessary to test the ability of Rosgen's system to usefully partition channel types.

ACKNOWLEDGEMENTS

Advisory Panel
The Service and SHA have obtained the cooperation of the state and federal agencies involved in the review of highway projects through a formal Partnering Agreement and formation of a Maryland Stream Survey Advisory Panel. It is important that all interested agencies agree to the approach and objectives of the survey. The agencies agreed that, upon review and acceptance by the Advisory Panel, the information would provide a useful tool for evaluating the effects of proposed projects in channel, wetlands, and flood plains.

Maryland Department of the Environment, Water Management Administration
Maryland Department of Natural Resources, Chesapeake and Coastal Watershed Service
Maryland State Highway Administration
Natural Resources Conservation Service
U.S. Army Corps of Engineers, Regulatory Branch
U.S. Federal Highway Administration, Maryland Division
U.S. Fish and Wildlife Service
U.S. Forest Service

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SYMBOLS AND ABBREVIATIONS

Symbol	Definition
A_{xs}	Cross-sectional area
d	Mean bankfull depth
D_{50}	Median particle size
D_{84}	Particle size at which 84% of sample is smaller
DA	Drainage area
"f"	Darcy-Weisbach friction factor
g	Gravitational acceleration
MP	Main Piedmont region
MWR	Meander width ratio
"n"	Manning's roughness coefficient
NEP	Northeast Piedmont region
p	Probability
Q	Discharge
R	Hydraulic radius
Rc	Bend radius
RI	Riffle interval
s	Second
S	Slope
SC	Silt-clay
W	Bankfull width
ρ_s	Density of sediment
ρ_w	Density of water
τ_{cr}	Critical shear stress
τ_o	Boundary shear stress

INTRODUCTION

Bankfull discharge is not necessarily of constant frequency or the most effective flow. Channel form is the product not of a single formative discharge but of a range of discharges, which may include bankfull, and of the temporal sequence of flow events. However, the bankfull channel is the one reference level, which can reasonably be defined, and it remains intuitively appealing to attach morphologic significance to bankfull flow (Knighton, 1984).

The U.S. Fish and Wildlife Service and Maryland State Highway Administration (SHA) signed a cooperative agreement to develop regional relationships of bankfull cross-section dimensions versus drainage areas for some of the physiographic provinces within Maryland. The short-term goal of this agreement is to develop appropriate relationships of stream characteristics on a statewide basis. The long-term goal is to provide the SHA with the information needed to develop hydraulic designs of culverts and small bridges that maintain as much as possible the natural bankfull channel dimensions. Maintenance of natural channel conditions should minimize disturbances to existing stable stream channels and their associated flood plains and wetlands, and help alleviate unstable conditions caused by crossing structures. The Pilot Study reported here has two primary objectives: development of field and office protocols for stream surveys and documentation of preliminary evidence that regional relationships exist.

Relationships between discharge and channel cross-section dimensions, termed "downstream hydraulic geometry", have been recognized for some time (Inglis, 1949; Blench, 1957; Leopold & Maddock, 1953; Wolman, 1955; Nixon, 1959; Hey & Thorne, 1986). For obvious reasons, drainage area is identified as a consistent and convenient surrogate for discharge in the development of such relationships (Leopold and others, 1964). Similarly, several workers (Leopold & Wolman, 1960; Hey, 1983; Williams, 1986), have identified functional relationships between channel size (usually expressed as width) and planform patterns, channel boundary materials and channel shape (Schumm, 1960), and bed roughness and flow resistance (Limerinos, 1970; Hey, 1979). Because of the number and complexity of determining variables actually underlying these relationships, it is widely recognized that such relationships hold only within relatively homogeneous regions or for specified ranges of state variables (Leopold & Maddock, 1953; Leopold et al, 1964). Regional characteristics of interrelated variables such as precipitation, soils, and vegetation strongly influence the specific quantitative nature of down-stream hydraulic geometry, planform, and resistance relationships.

The value of a quantitative understanding of hydraulic geometry relationships for water resource planning and management has long been recognized (Dunne & Leopold, 1978). For river engineering purposes, particularly in the field of river restoration, regional channel geometry relationships are widely viewed as an important tool for both assessment and design procedures (U.S. Army Corps of Engineers, 1994; Rosgen, 1994, 1996a; Brookes & Shields, 1996; Thorne et al., 1997). A number of more-or-less regional relationships between discharge or drainage area and channel dimension have been developed for a variety of geographic areas in the Eastern United States (Wolman, 1955; Brush, 1961; Kilpatrick & Barnes, 1964; Leopold et al., 1964). Unfortunately, a lack of consistency among these authors in selection of formative, or dominant, discharge, and definition of the bankfull channel makes comparison among these relationships difficult. In addition, the most accessible set of regional relationships between drainage area and channel geometry for the Eastern U. S., that published by Leopold and his coworkers (Leopold, Wolman, & Miller; Dunne & Leopold; Leopold, 1994), lacks any expression of the range of

expected variability. For both assessment of stream channel condition and design of channels that approximate "natural" states, an understanding of the range of natural variability between drainage area and channel dimensions is as important as knowledge about central tendencies.

Engineers, geologists, and geomorphologists have long resorted to classification schemes as a means of imposing order on the inherently variable physical nature of rivers. While early attempts focused on fairly coarse (Leopold and Wolman, 1957) or more finely distinguished (Brice, 1960) characterizations of planform, later systems have become more comprehensive and process-based by incorporating cross-section, longitudinal profile, or channel material characteristics (Schumm et al., 1984, Simon, 1989; Montgomery and Buffington, 1993; Whiting and Bradley, 1993; Rosgen, 1994, 1996a). One of the great attractions of these process-based approaches to classification is that, beyond their use for mere organization of information, some suggest they have predictive value. Engineers and resource managers want and need conceptual tools for predicting the nature, direction, and rate of river adjustment processes. Not surprisingly, a great deal of discussion revolves around the merits and drawbacks of specific systems.

Rosgen (1996a) developed his system to address specific, applied objectives related to conditions and processes: to predict behavior from appearance, to develop specific hydraulic and sediment relationships for given stream types and states, to provide a mechanism for extrapolation of site-specific data to streams of similar type, and to provide a consistent frame of reference to aid communication about river morphology and condition among various disciplines. While Rosgen's system has many adherents, particularly within resource management agencies, others question both the general applicability of the system throughout the U. S., and its ability to meaningfully represent basic fluvial processes (Miller and Ritter, 1996). In partial response to these criticisms, Rosgen (1996a,b) has explicitly reiterated the need for regional refinement and calibration of the basic system.

In this Pilot Study, we conducted surveys of 25 gaged stream reaches in the Piedmont hydro-physiographic province of Maryland to test for relationships between:
1) drainage area and bankfull discharge,
2) drainage area and bankfull channel dimensions,
3) channel size and planform and riffle-pool attributes,
4) bankfull discharge and channel cross-section dimensions; and
5) relative roughness and flow resistance.
We also classified each reach according to the Rosgen classification system of natural rivers and examined the utility of such classification for explaining the observed variability in the above relationships.

Because of concerns raised by the Advisory Panel regarding the issue of whether the gage survey sites represented reference reaches, the information related to channel size and planform, riffle-pool attributes, and other discussions on channel geometry have been deleted from the report.

METHODS
Selection of Gage Sites
We selected twenty-one sites (Figure 1) for survey from the network of active gage sites operated by the Maryland-Delaware-D.C. District of the USGS in the Piedmont hydro-

physiographic region in Maryland. As most of the active stations have drainage areas greater than 10 mi^2, we selected four additional stations from among the inactive gages, previously operated by the USGS. At these four inactive sites, the USGS collected contemporary discharge measurements and prepared revised stage-discharge ratings. Table I lists the name, station number and drainage area for sites included in the analyses. Appendix A, *Site Characteristics for Selected USGS Gage Stations in the Piedmont Physiographic Province*, provides a complete description of each site.
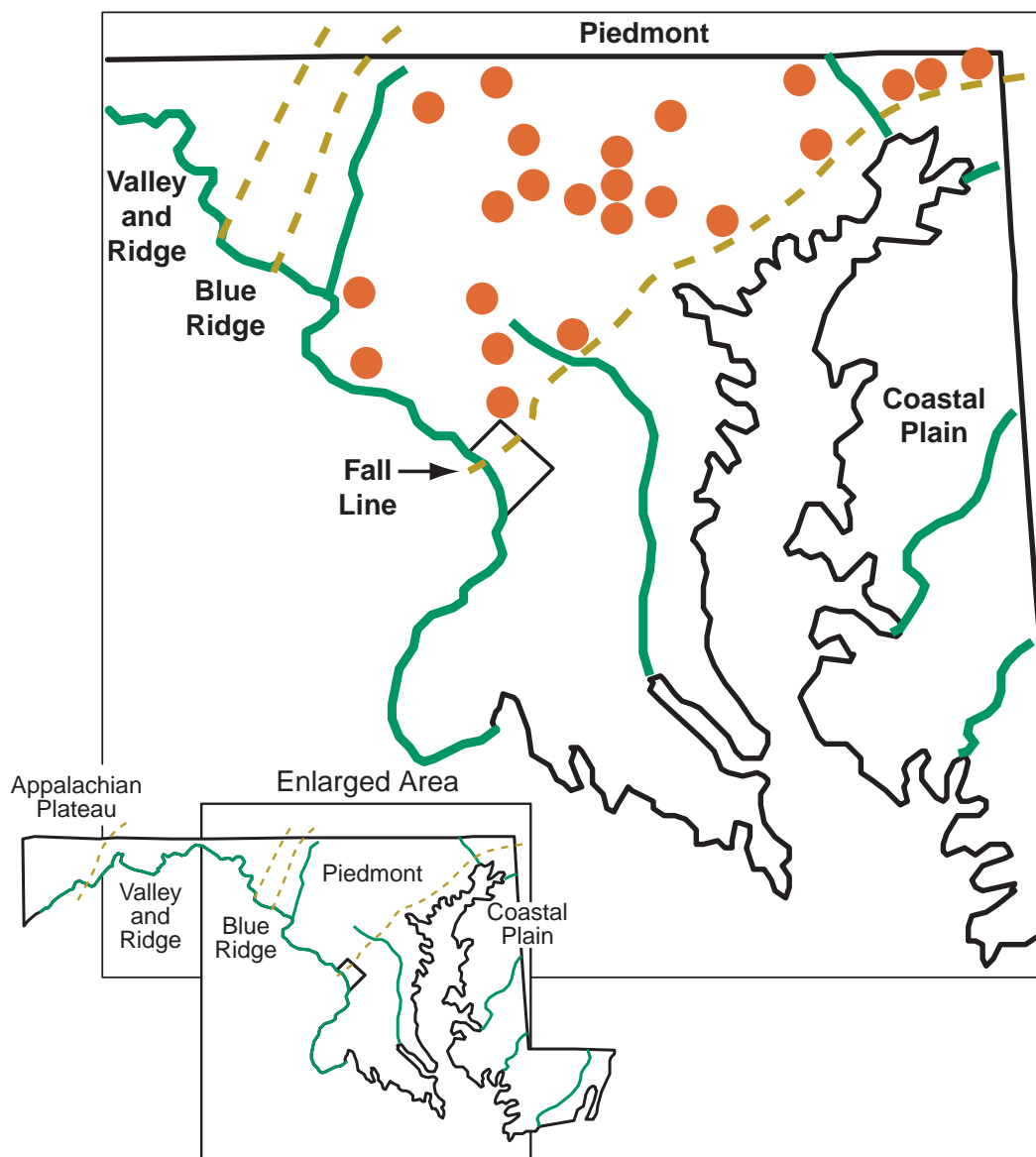
Figure 1. Survey site locations in the Maryland Piedmont hydro-physiographic province.

Table I. USGS Gage Stations in Maryland Piedmont Survey		
USGS Gage Site (all in MD)	USGS Station #	Drainage Area (mi^2)
Baisman Run @ Broadmoor	1583580	1.47
Basin Run @ Liberty Grove	1579000	5.31
Beaver Run near Finksburg	1586210	14.00
Beaverdam Run @ Cockeysville	1583600	20.90
Bennett Creek @ Park Mills	1643500	62.80
Big Elk Creek @ Elk Mills	1495000	52.60
Big Pipe Creek @ Bruceville	1639500	102.00
Cranberry Branch near Westminster	1585500	3.40
Deer Creek @ Rocks	1580000	94.40
Hawlings River near Sandy Spring	1591700	27.00
Jones Falls @ Sorrento	1589440	25.20
Little Falls @ Blue Mount	1582000	52.90
Little Patuxent River @ Guilford	1593500	38.00
Long Green Creek @ Glen Arm	1584050	9.40
Morgan Run @ Louisville	1586610	28.00
Northeast Creek @ Leslie	1496000	24.30
NW Br Anacostia River near Colesville	1650500	21.10
Patuxent River near Unity	1591000	34.80
Piney Creek @ Taneytown	1639140	31.30
Seneca Creek @ Dawsonville	1645000	101.00
Slade Run near Glyndon	1583000	2.09
Western Run @ Western Run	1583500	59.80
Winters Run near Benson	1581700	34.80

The criteria for inclusion of all sites included the following:
- Intact staff gage or recoverable benchmarks referenced to staff gage elevations.
- Unarmored channel near the gage, capable of adjusting to the flow regime. Natural bedrock vertical and horizontal controls were acceptable.
- Sufficient length (10-20 bankfull widths) of channel for a longitudinal profile survey through the gage location.
- An acceptable study reach (ideally at least 20 bankfull widths) near the gage that had not been obviously channelized or otherwise altered in the recent past. In some cases, there was evidence of historic channel manipulations, but the age of vegetation on the banks indicated that several decades had elapsed since the work was completed. Some study reaches also had constructed revetments (boulder or gabion) along short stretches of bank, but in all such cases, the opposite bank was natural and able to adjust to the flow regime.
- Ten years of record, to permit adequate estimation of flood frequency distributions.

At 13 sites, gage reaches and study reaches are not contiguous. This is usually due to significant stretches of artificial channel control (rock, gabion, or concrete revetment), influence on the channel from the bridge crossing (usually backwater, scour, or channelization), or an insufficient length of channel with homogenous characteristics. For these sites, we selected separate study reaches with sufficient length (as above) of homogenous channel upstream or downstream of the gage reach.

We have eliminated two sites, Cattail Creek near Glenwood, Maryland (USGS Station #1591400) and Piney Run at Dover, Maryland (USGS Station # 1583100) from the final analysis. Cattail Creek plots well outside the 95% confidence limits for the remaining data, and on this basis we consider it an anomalous outlier and exclude it from further analyses. Piney Run's rating table has been unstable compared to earlier records and since reinstatement of the gage by the USGS. Recently, the USGS has identified a significant channel modification downstream of the gage, which may be causing a backwater at the gage.

One important consideration of stability in the Piedmont is the duration of land use changes. Jacobson and Coleman (1986) suggest that the stratigraphic record show evidence of channels deepening. They and others (Costa 1975, Trimble 1974, and Wolman 1967) suggest that the hydrology and sediment supply of the Piedmont watersheds have varied over the last 250 years based on the history of land use, with peaks in agriculture from 1900 to 1910. These land uses have clearly impacted the Piedmont channels. Our task was to determine, on-site, whether to use a stream reach for the survey, and that the present bankfull conditions are representative of a stable, dynamic channel. It was not to determine the rate of change of channel morphology in the present day.

The gaged sites do not necessarily represent reference reach sites and some of the streams may represent transition stream types. The relationships provide no information about chemical or ecological parameters, and do not necessarily represent "good" habitat conditions. In fact, the low amounts of large woody debris in the surveyed channels are likely an indication of relatively poor habitat conditions. From our experience in the Piedmont physiographic region, not only at gaged sites but also at other sites as well, many streams represent borderline or transition reaches. This may very well be a result of recent alteration but most certainly is a result of past land use practices, in particular agriculture and the resultant floodplain fills.

Preliminary Analysis of Gage Records
The USGS provided records of station descriptions and analyses, level notes, log-Pearson type-III flood frequency distributions (annual maximum series), and stage-discharge relationships for each of the selected gage stations. Flood frequency distributions, provided as exceedance probabilities calculated according to *Guidelines for Determining Flood Flow Frequency* (Interagency Advisory Committee, 1982), were transformed via inversion into recurrence intervals, and plotted on log-Pearson type-III probability paper. The SHA provided land use and cover characteristics, including an estimate of the percent imperviousness, from 1994 Landsat and Spot images using the computer program *GIS-Hydro* (Ragan, 1991).

Field Surveys
Below, we provide brief summaries of study procedures; detailed descriptions of specific survey methods are in Appendix B *Protocols for Field Surveys at Gage Stations*.

Bankfull Channel: Definition and Indicators
The concept of the "bankfull" channel has been problematic. At the simplest level, the term is used to describe the point of "incipient flooding": that elevation at a cross-section at which a rising water level just begins to flow out of the channel and over the floodplain (Wolman and Leopold, 1957). Much discussion has revolved around the degree to which this morphologic

bankfull flow corresponds to the more process-based dominant and effective flows. While some studies have reported close agreement between these various discharges (Andrews, 1980, Leopold, 1992), other workers have reported contrasting results (Pickup & Warner, 1976). A wide variety of approaches to measuring or estimating the relevant variables involved makes objective comparisons among the various studies difficult (see excellent summaries in Knighton, 1984 and Richards, 1982).

Not least of these problems is that of defining and identifying the limits of the bankfull channel. While "the elevation at which a rising water level just begins to inundate the floodplain" is conceptually appealing, in practice the identification of such a point is fraught with difficulty. There is wide agreement that the floodplain of interest is that which is actively building and is maintained by the river under current conditions of discharge (both water and sediment), as opposed to portions of the valley flat that are not altered by river flows. There seems equally wide agreement that the interface between channel and floodplain can be difficult to distinguish in reaches that lack the well-developed depositional bars where new floodplain surfaces occur. Even with a prominent floodplain, the point of incipient flooding can become subjective. Local characteristics of over-bank flow patterns, deposition, and vegetation interact to produce a floodplain surface that is anything but flat, particularly at a scale encompassing tenths of a foot. At this scale, the floodplain surface adjacent to the active river channel is a heterogeneous mosaic of humps and depressions. At more geologically confined reaches, and in reaches that have undergone considerable incision, a well-developed floodplain may not even be present. There is thus a need to carefully define and describe those attributes, or indicators, used to delineate the bankfull channel in any specific reach.

An often-expressed assumption is that the channel is adjusted to the range of flows that just fill its banks (Knighton, 1984). A fine-scale ability to delineate the transition from actively maintained channel to non-channel is then critical if one wishes to identify the dimensions of self-maintained rivers. A discrete transition from a relatively vertical channel bank to a relatively flat floodplain is the best indicator of bankfull elevation. As noted above, the floodplain-channel interface is often variable, or a floodplain is irregularly present or even absent. Under such circumstances, other indicators of a channel maintaining stage (or narrow range of stages) are required. Because the primary mechanisms of channel maintenance are erosion and deposition, the most indicative characteristics should also be representative of such processes. For channels that are not changing in dimension, point bar (and therefore floodplain) building requires balancing erosion. The process discontinuity produced by a transition from in-bank to over-bank flow can result in a change in the relative erosive abilities of flows working on the channel banks, such that erosion scars may be found on higher banks (i.e., where the channel impinges on a terrace) at elevations coincident with those of channel-floodplain transitions. These erosion indicators manifest on a vertical surface as wear lines, or are acute or obtuse changes from vertical in bank slope. Lateral depositional features other than point bars are often observed, with elevations coincident with the point bar-floodplain transition. These lateral depositional areas may be relatively long (many channel widths), or short features developed where the channel has become locally widened.

Additional, non-morphological, characteristics of bankfull elevation have been used, such as discontinuities in the distribution and composition of vegetation (Woodyer, 1968; Nunnally, 1967), and the vertical distribution of fines in the bank materials (Nunnally, 1967). However, subsequent studies have suggested that these characteristics are too variable for use as primary

indicators, and should instead support or refine bankfull delineations based on morphologic criteria (Williams, 1978; Richards, 1982).
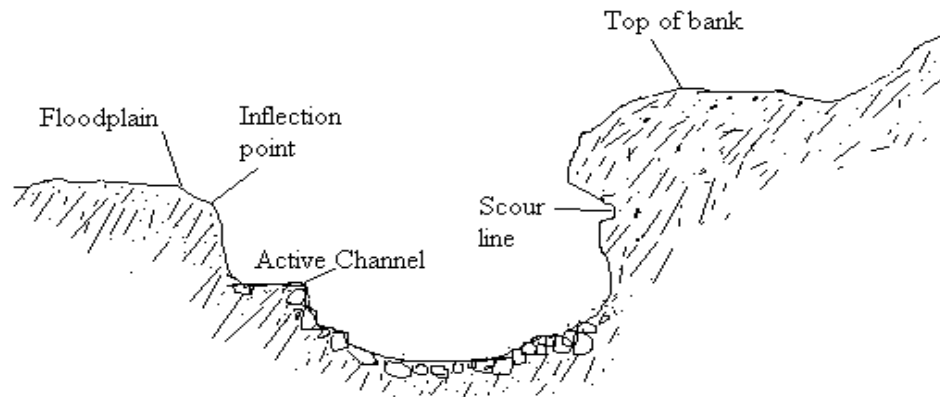
Figure 2. Typical bankfull indicators.

We used the following indicators to identify potential bankfull elevations (Figure 2):

> *Floodplain break:* a discrete transition from near vertical to near horizontal; used on straight reaches or on bends lacking point bars. In some cases, (where the stream in not entrenched or incised) the floodplain break may also be the top of bank.

> *Inflection point*: where the transition from near vertical bank to near horizontal floodplain is not relatively discrete, but instead occurs over a transitional zone often composed of one or more obtuse slope breaks over a vertical distance of several tenths of a foot, the inflection point is the lowest identifiable break in slope.

> *Scour line*: a wear mark on a vertical bank, or a discrete break in slope (acute or obtuse) of the channel bank, distinguished from an inflection point by being further down from the top of bank.

> *Depositional bench*: the flat surface, or highest elevation, of a lateral depositional surface other than a point bar. This may also be referred to as the active channel.

> *Point bar*: the transition point from inclining point bar surface to horizontal floodplain surface.

Prior to field surveys, we conducted reconnaissance investigations to identify and flag bankfull indicators (described above) at each site. For the 13 sites with noncontiguous gage and study reaches, we performed separate surveys in each reach, using both a laser level and tape or a survey total station, as follows.

Gage Reaches

We surveyed longitudinal profiles, referenced to gage datum and including the gage location, for bankfull indicators, bed and water surface elevations. We used these profiles to estimate the gage datum elevations for each particular series of indicators. We also surveyed a cross-section, at a riffle or a run in close proximity to the gage. We examined vertical profiles from each survey for evidence of a relatively linear trend parallel to the line of water surface elevations. We considered linear groups of points with similar relative elevations above water surface to indicate potential bankfull elevations.

Study Reach Surveys

We conducted surveys at study reaches to quantify average reach slope, the proportional distribution of channel units, a visually representative cross-section at a riffle or run, particle size distributions for reach channel materials, particle size distributions at the cross-section location, bank materials at the cross-section location, and planform characteristics. We used three different survey approaches: at 13 reaches we used a laser level to measure average stream slope and a riffle cross-section; at five reaches, we used a laser level to survey a detailed longitudinal profile defining individual channel-unit facets (pools, riffles, runs) and a riffle cross-section; and at five reaches, we used a survey total station instrument to map the longitudinal profile, planform, and several cross-sections through riffles and pools.

We quantified reach particle size distributions for the channel boundary materials as one of the criteria for Rosgen classification, using Rosgen's (1996a) modification of the Wolman pebble count method. We determined a particle size distribution for the cross-section riffle in each reach in a similar manner by sampling ten transects spaced at equal intervals along the riffle. We assigned sand and smaller particles to a size range by comparing sampled grains with standard size fractions glued on a "sand gauge". We collected bulk samples from each bank at the riffle cross-section locations to determine particle size distributions for bank materials. In the laboratory, we combined and air-dried the samples, removed macroscopic organic litter such as leaves and twigs, mechanically shook the sediments through a series of standard sieves, and weighed the separated size fractions. While we did collect bank samples at each cross-section, the bank sample was only used to characterize the composition of the banks and was in no way used to weight the reach average pebble distribution.

In each study reach, we surveyed one visually representative riffle or run to determine cross-section dimensions and flood prone widths. Rosgen has defined the flood prone width as the distance across the valley at an elevation above the thalweg equal to twice the maximum bankfull depth. We located the flood prone elevations on each side of the stream with a laser level and either measured the distance with a tape, estimated the distance with a topographic map (where the distance was the approximate width of the floodplain), or included flood prone elevation points in a total station survey.

We used a total station instrument to quantify the planform characteristics of each reach by surveying sufficient points at the bankfull elevation, water surface, thalweg, and tops of banks to map the meander pattern of the channel. Our measure of sinuosity is the "total" sinuosity as defined by Mueller (1968), and as such incorporates components of sinuosity due to both geologically constrained (topographic) and alluvial (hydraulic) meandering.

Data Analysis

For laser-level surveys, we used the calculation and graphing capabilities of the software program *Excel* (Microsoft Corp., Redmond, WA) to determine cross-section and slope parameters, and plot detailed longitudinal profiles. We used the software program *Terra Model* (Spectra Precision Software, Inc., Atlanta, GA), to produce planform, longitudinal and cross-section plots from the total station surveys. We measured planform parameters, such as bend radii and meander lengths, using analytical geometry capabilities of the software. We exported the cross-section data from *Terra Model* to customized *Excel* spreadsheets designed to automatically calculate the hydraulic parameters width, mean depth, cross-sectional area, and hydraulic radius.

We classified each of the reaches according to the Rosgen system, using the delineative criteria of entrenchment ratio, width/depth ratio, sinuosity, water surface slope, and median particle size. Because the variability in these parameters among streams is continuous while the stream classification is composed of discrete types, some ambiguity can occur at the interface between types. To classify streams under such circumstances, we compared the observed values of each of the parameters with the frequency distributions presented by Rosgen (1996b) for each stream type.

We performed calculations for statistical analyses using either *Excel*, or *Minitab* (Adobe Systems, Inc., State College, PA). We used the Anderson - Darling test to examine data for departures from the normal distribution; an F-test to examine for variances for homogeneity; t-tests to compare regression slopes and intercepts (Zar, 1999). For all tests, we used an a-priorie $\forall = 0.05$ unless otherwise noted.

RESULTS AND DISCUSSION

Summary of General Site Characteristics

Summaries of surveyed characteristics for each study reach are in Appendix A. The 23 study reaches used in the analysis are distributed throughout the Piedmont region of Maryland (Figure 1), and are located in 10 major river basins and 7 counties (Table II). Drainage basin sizes range from 1.47 mi^2 – 102 mi^2, and Shreve (1967) magnitudes vary between 2 - 189. Although we attempted to use sites with low degrees of basin development, the percent imperviousness of the watersheds draining to the study reaches ranges from 2 - 21%. Seventeen of the 23 sites have less than 12% imperviousness.

River Basin	No. Sites	County	No. Sites	Drainage Area (mi^2)	No. Sites	Percent Impervious	No. Sites	Shreve Mag.	No. Sites
Anacostia	1	Baltimore	7	<10	5	0-3	4	0-20	6
Bush	1	Carroll	5	10-20	1	3-6	8	20-40	4
Elk	1	Cecil	3	20-30	6	6-9	5	40-60	3
Gunpowder	6	Frederick	1	30-40	4	9-12	0	60-80	4
Monocacy	3	Harford	2	40-50	0	12-15	2	80-100	2
Northeast	1	Howard	1	50-60	3	15-18	1	100-120	0
Patapsco	4	Montgomery	4	60-70	1	18-21	2	120-140	2
Patuxent	3			70-80	0	21-24	1	140-160	0
Seneca	1			80-90	0			160-180	1
Susquehanna	2			90-102	3			180-200	1

Table II. Summary of site location and basin characteristics for study reaches at USGS gage stations in the Maryland Piedmont.

We suspect that many of the gage reaches at road crossings were altered at some time in the past by channelization or realignment. While most gages themselves are located at bridges, the actual study reach and cross-section measurement locations were located away from the influence of these structures. Few channels have escaped manipulation or anthropogenic influence over the past 350 years in not only Maryland but also the entire mid-Atlantic. However, channel recovery does occur, and there are many examples of stable channels throughout the mid-Atlantic. We do not have information regarding rate of degradation from channelization or rate of recovery. This requires further examination with more intensive sampling at known disturbance sites. While we often see degradation at bridges due to channel confinement and increased velocities through the bridge, quite often it is a localized effect and does not proceed far up- or downstream. We have seen instances of exposed footings but an otherwise stable channel away from the bridge site. While we do not consider any of the represented survey sites in a state of rapid adjustment, we have no information about the relative rates of lateral or down-valley meander migration.

Rosgen Stream Types

The 23 reaches partition into three Rosgen Level II stream types (Table III). There are nineteen C-type, three E-type, and one B-type channels. The bed material varies in the reaches with two boulder/bedrock channels, eight gravel channels, nine gravel/bedrock channels, two sand channels, and two sand/bedrock channels. Sixty-eight percent of the sites had non-uniform reach-average pebble count distributions. In the case of a bimodal or skewed distribution, Rosgen (1996) recommends using the dominant size class sampled, rather than the percent cumulative of the channel material size group, for classification. Rosgen also states that the D_{50} of the riffle size distribution often mirrors the dominant particle size of the reach.

Figure 3 shows the Piedmont stream type delineative values or, where possible, averages and ranges, plotted with Rosgen's average values and ranges for similar stream types (Figure 3). The Piedmont E streams have lower entrenchment and greater width/depth values than the average values reported by Rosgen although the Piedmont E streams are well within the range of Rosgen's data set. The C streams, on the other hand, have higher entrenchment but lower width/depth values than same stream types in Rosgen's data set, with the Piedmont C5 streams outside the range of Rosgen's data set (1996a) for entrenchment and width/depth (Figure 3).

Across all stream types, the Piedmont channels have lower sinuosities than reported by Rosgen (Figure 3). All stream types in the Piedmont have slopes within the ranges reported by Rosgen (Figure 3). Piedmont C5 channels have higher average slopes compared with Rosgen's data set for the same stream type, while the average slope for Piedmont C4 channels is quite close to that reported by Rosgen. Not unexpectedly for the limited number of samples per stream type, and the restricted geographic range, the ranges of observed slopes in Piedmont channels is markedly less than the ranges reported by Rosgen with the exception of C4 streams (the largest representative stream type surveyed) (Figure 3).

Table III. Maryland Piedmont survey sites - Rosgen stream classifications.							
USGS Gage Site	Entrenchment Ratio	Width / Depth Ratio	Sinuosity	Water Surface Slope	Meander Width Ratio	D50 (mm)	Particle	Rosgen Stream Type
Baisman Run @ Broadmoor	24.23	11.39	1.29	0.0160	4.44	9.47	medium gravel	C4
Basin Run @ Liberty Grove	7.04	27.04	1.40	0.0059	1.88	10.31	medium gravel	C4
Beaver Run near Finksburg	3.13	15.49	1.06	0.0050	2.15	36.63	very coarse gravel	C4/1
Beaverdam Run @ Cockeysville	10.73	11.52	1.13	0.0008	2.20	0.63	coarse sand	C5/1c-
Bennett Creek @ Park Mills	3.26	17.41	1.11	0.0019	1.94	16.95	coarse gravel	C4/1
Big Elk Creek @ Elk Mills	5.25	17.57	1.04	0.0014	2.71	17.97	coarse gravel	C4/1
Big Pipe Creek @ Bruceville	3.69	14.32	1.45	0.0013	7.25	20.20	coarse gravel	C4/1
Cranberry Branch near Westminster	17.79	11.72	1.60	0.0061	4.19	6.68	fine gravel	C4
Deer Creek @ Rocks	1.61	21.54	1.22	0.0021	4.95	19.04	coarse gravel	B4/1c
Hawlings River near Sandy Spring	14.17	11.20	1.19	0.0022	2.28	0.36	medium sand	C5
Jones Falls @ Sorrento	3.63	15.74	1.13	0.0016	1.93	7.70	fine gravel	C4
Little Falls @ Blue Mount	4.61	13.79	1.09	0.0019	3.00	18.73	coarse gravel	C4
Little Patuxent River @ Guilford	9.60	9.88	1.37	0.0005	5.34	0.71	coarse sand	E5
Long Green Creek @ Glen Arm	4.22	22.95	1.04	0.0165	1.06	132.81	large cobble	C2/1*
Morgan Run @ Louisville	3.42	16.35	1.18	0.0052	6.04	32.00	very coarse gravel	C4/1
Northeast Creek @ Leslie	3.12	17.01	1.11	0.0120	7.41	106.94	small cobble	C2/1*
NW Br Anacostia River near Colesville	14.71	8.32	1.06	0.0017	1.93	1.13	very coarse sand	E5/1
Patuxent River near Unity	8.23	13.37	1.26	0.0021	5.96	14.00	medium gravel	C4
Piney Creek @ Taneytown	9.12	17.41	1.47	0.0025	5.08	14.54	medium gravel	C4/1
Seneca Creek @ Dawsonville	12.02	11.11	1.05	0.0014	1.48	2.83	very fine gravel	C4
Slade Run near Glyndon	33.76	9.11	1.07	0.0120	1.89	10.69	medium gravel	E4
Western Run @ Western Run	21.10	18.13	1.47	0.0024	7.96	4.28	fine gravel	C4/1
Winters Run near Benson	3.73	15.19	1.14	0.0052	3.54	26.42	coarse gravel	C4/1

* Bimodal distribution, largest number of observations is in boulder size class.
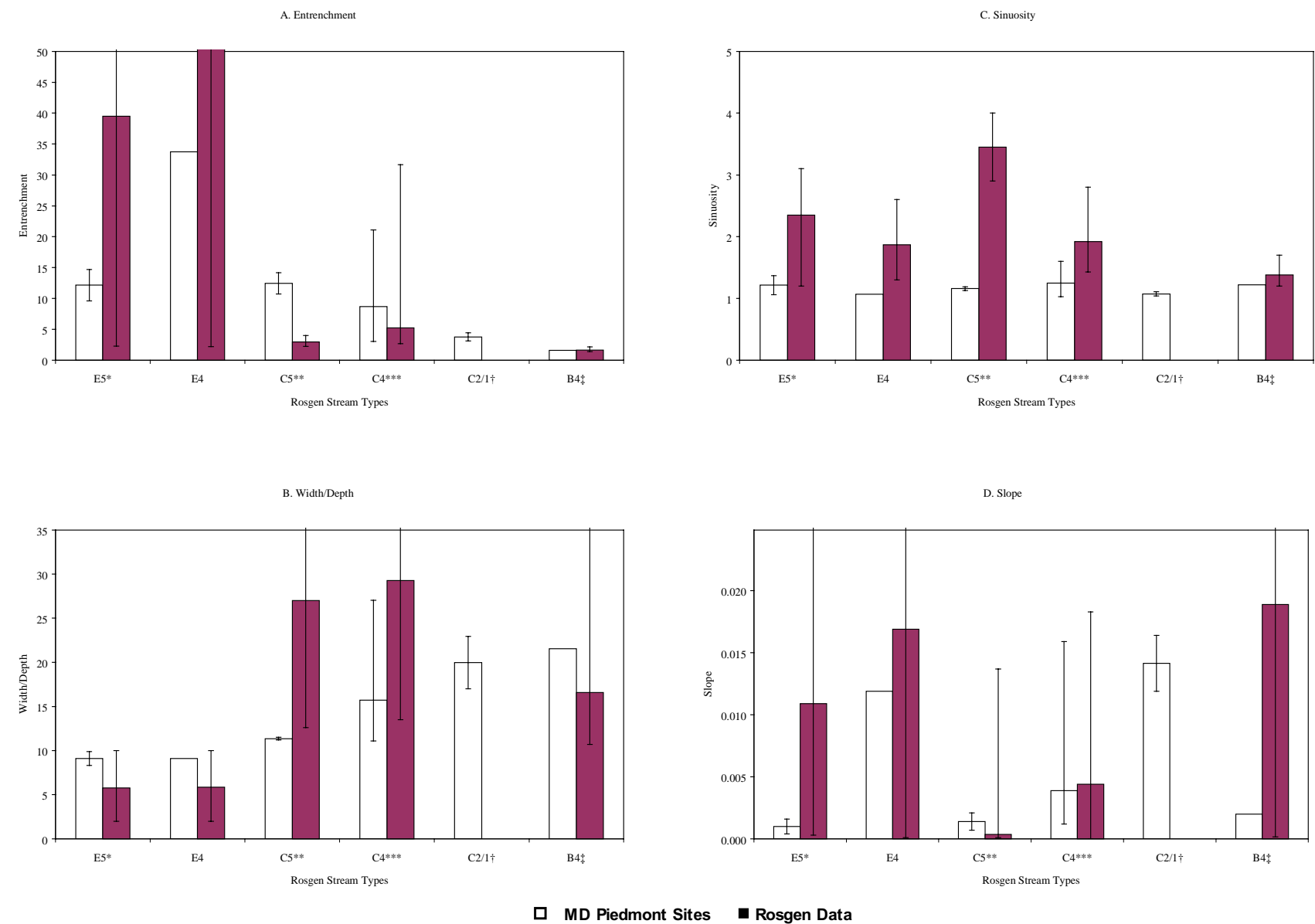
Figure 3. Maryland Piedmont surveys compared with Rosgen Classification criteria (Rosgen 1996).

* Maryland Piedmont sites include E5 and E5/1. ** Maryland Piedmont sites include C5 and C5/1c. *** Maryland Piedmont sites include C4/1.
† No Rosgen C2/1 data available. ‡ Maryland Piedmont site is a B4/1.

Discussion

In that all the reaches we surveyed classified to a specific stream type, the results of this study support the applicability of the Rosgen classification system to Maryland Piedmont channels. However, a limited number of stream types were observed at the gage stations in the Piedmont – most of the channels classified as C type streams, and of these C4 (gravel) – type channels were predominant. For the Maryland Piedmont streams surveyed, there are insufficient numbers of different stream types to allow examination of regional relationships partitioned by major Rosgen stream types. The low degree of variability in width/depth ratios across all streams results in a high number of channels falling in the region of overlap between the major stream types. The USGS gage station survey sites do not necessarily represent "stable, reference reach sites" and some of the surveyed streams may represent transition stream types. From our experience in the Piedmont physiographic region, not only at gaged sites but also at other sites as well, many streams represent borderline or transition reaches. In some cases, this may very well be a result of recent alteration but most certainly is a result of past land use practices, in particular agriculture and the resultant floodplain fills.

To classify some streams, it was necessary to compare the site data with the distribution of criterion values reported by Rosgen (1996a) for specific stream types, rather than with the broad delineative criteria, because the streams did not fit neatly into the broad categories. Several factors contributed to this problem. First, the width/depth for the Piedmont streams surveyed tends to be low, probably due to the cohesive bank materials and stabilizing influence of riparian vegetation. Thus, 10 of the 23 sites had width/depth ratios in the range 10-14, making the distinction between C and E stream types more complicated. Second, sinuosities of the streams are also low, and this in turn influences the secondary criterion of meander width ratio.

For example, survey results from Hawlings River and Little Patuxent River overlapped at the cut-off values in the broad level delineations. Table IV lists the broad delineative criteria values for C and E stream types (with the applicable "adjusted" value shown in parentheses) and the observed range of parameter values for C5 and E5 stream types reported by Rosgen for his 450 reach data set (Rosgen 1996a). The following describes the process by which we assigned stream types for Hawlings River and Little Patuxent River.

We initially classified Hawlings River as an E5 but changed it to a C5 following review by Rosgen (written commun., 1999). The measured median particle size distribution dictates that the numeric component of the stream type will be a "5" or sand. The survey reach has an entrenchment of 14.2, meeting the broad criteria for both C and E stream types. The width/depth ratio is 11.2 fitting the E-stream type broad delineative criteria but on the borderline with C-stream types (although within the variability ± 2.0). The sinuosity is 1.19, which fits the broad delineative criteria for the C-stream type. The slope is 0.0022, fitting both the broad E-and C-stream type criteria. The confinement at Hawlings River is 2.2, well below both the C and E averages, but near the range of C (4 – 20). Hawlings River is a pool/riffle/run stream with some mid-channel and point bar depositional features. Because the survey data more closely meets the broad criteria of C stream types, the stream type classification is a C5.

Little Patuxent River also has a measured median particle size distribution of sand designating the numeric component of "5". The entrenchment of 9.6 meets the broad criteria for both E and C stream types. However, it is well outside the range for C5 stream types and in the range of E5 stream types. The width/depth ratio is 9.9, fitting the E-stream type broad delineative criteria

and on the borderline with C-stream types (although within the variability ± 2.0). The width/depth ratio at Little Patuxent River falls below the ranges for C5 but within the E5 stream types. The sinuosity is 1.37 (the fifth highest measured), which fits the broad range of the C-stream type delineative criteria of >1.2 ± 0.2 units but also fits into the E category >1.5 ± 0.2 units. The slope is 0.0005, fitting the broad E criteria and the Cc- criteria. The confinement at Little Patuxent River is 5.04 below both the E- and C-stream type averages, but in the range of C (4 – 20). Little Patuxent River is a pool/riffle/run stream with poorly defined point bar depositional features. While the stream is on the borderline between C and E, this channel is more typical of an E5 stream type than a C5, based on the range and average data.

Table IV. **Classification by comparison with Rosgen delineative criteria ranges**. Comparison of ranges of delineative criteria values observed by Rosgen (1996a) and delineative criteria cut-offs for major stream types. Parenthetical values in the criteria cut-off columns are the criteria limits after the adjustment allowed by Rosgen.				
	C5		E5	
Criteria	**Rosgen Range**	**C Criteria Cut-off**	**E Criteria Cut-off**	**Rosgen Range**
Entrenchment (flood prone width/bankfull width)	2.25 - 4.0	>2.2 (2.0)	>2.2 (2.0)	2.27 - 200
Width/Depth	12.6 - 46.0	>12 (10)	<12 (14)	2.0 - 10.0
Sinuosity	2.9 - 4.0	>1.2 (1.0)	>1.5 (1.3)	1.2 - 3.1
Slope	.0002 - .0138	<.02	<.02	.0004 - .049

With the exception of Northeast Creek at Leslie with its boulder/cobble banks, all of the Piedmont study reaches have banks made up of sand. At some study reaches, there are broad low depositional features within the bankfull channel with a fine deposition on top. The bankfull to bankfull reach-average pebble count used to classify the stream reach materials may result in sand classifications for some streams in the Maryland Piedmont due to the sand composition of the banks and sidebars within the bankfull channel. However, classifying the streams, as sand bed streams would be misleading since the riffle compositions are obviously gravel. Thirty-two percent of the study sites have a uniform reach-averaged particle size distribution, while for the remaining non-uniform sites (68% or 17 sites), it was necessary to classify using the largest number of observations.

Overall, the Maryland Piedmont C4 and C5 channels were comparable to the range of delineative parameter values reported by Rosgen from North America and New Zealand. The departures, such as high entrenchment values in C5 channels compared with Rosgen's observed ranges are undoubtedly due to comparing data from markedly different geographic ranges. Of the five delineative criteria for the Piedmont sites, sinuosity was the parameter that least conformed to Rosgen's classifications, being uniformly low in all observed stream types. This is not as problematic as it might seem, as Rosgen has stated that sinuosity is of secondary importance in determining major stream type, compared to entrenchment, width/depth, and slope. To avoid undue confusion, the range of sinuosities expected for each stream type in the Piedmont may need to be refined. However, to adequately test this hypothesis, further observations will be needed, particularly for reaches less influenced by bedrock than the gaged streams surveyed in this study.

Rosgen (1994, 1996a) has published average and range values for dimensionless meander belt widths (BW/W_{bkf}), which he calls meander width ratios (MWR), by major stream type categories. The average MWR values for E and C type channels in the Maryland Piedmont are

strikingly lower than those presented by Rosgen (Figure 4). The difference is particularly large for E-type streams, where the average Piedmont MWR is almost one tenth of that reported by Rosgen, and for which there is no overlap in the ranges of MWR. The MWR for Piedmont C-type streams is approximately one third of that reported by Rosgen. Although there is some overlap between Piedmont and Rosgen MWR data for C-type streams, all Piedmont MWR observations are lower than the average reported by Rosgen. These lower confinement ratios appear to correspond to the rather low sinuosities observed in the Piedmont streams, perhaps due to past land uses as stated above. However, the existence of bedrock outcrops in the Piedmont (found at nearly 60% of the study reaches) may be the dominant confinement factor at the study reaches. The question also arises as to the length of channel used in measuring planform characteristics such as sinuosity. Although Rosgen (1996) indicates a study reach length of 20 to 40 bankfull-widths, this may be too short to examine planform characteristics such as sinuosity. We found that some parameters of the classification (entrenchment, width/depth, etc.) often changes beyond the study reach, suggesting that measurements of planform characteristics from aerial photographs may include different stream types. A comparison of the study reach sinuosity to the channel sinuosity taken from aerial photographs over a longer reach would be helpful in examining relationships between reach and overall channel pattern.
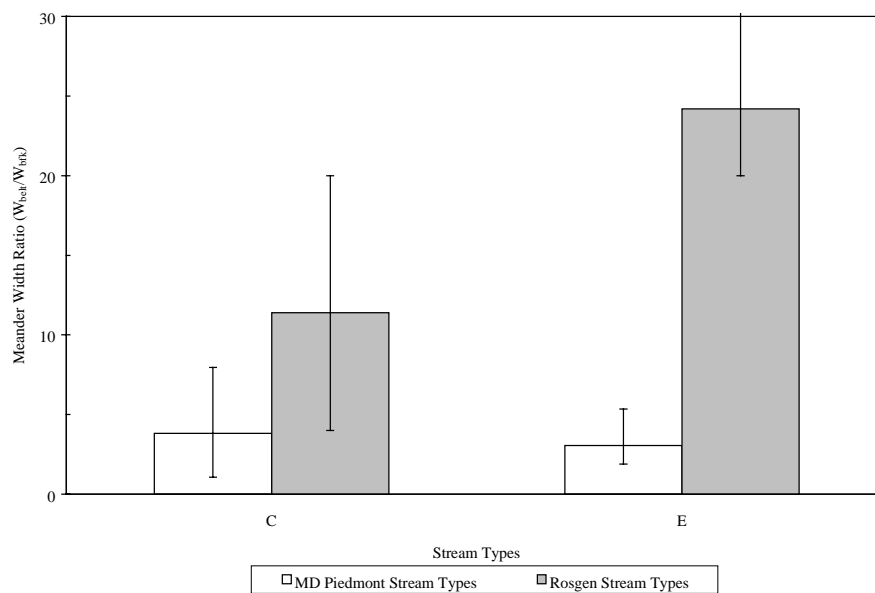
Figure 4. Maryland Piedmont survey sites meander width ratios compared to Rosgen stream types (1996).

Stream channels and drainage networks are highly dynamic, self-adjusting, systems, wherein morphologic changes occur through continuous, rather than discrete processes. Classification systems, by their very nature are composed of discrete entities, and are thus artificial constructs that, to varying degrees, ignore or minimize the importance of natural variability. This said, classification systems can be powerful tools for organizing voluminous and variable information, and perhaps even assist in identifying the meaningful outliers that can be used to test assumptions and dogma. Rosgen's (1994, 1996a) classification system for natural rivers is based on quantitative delineative criteria that characterize the physical attributes underlying hydraulic and sediment transport conditions in rivers. Rosgen developed the classification system to, in part: help predict a river's behavior from its appearance; provide a mechanism to extrapolate

site-specific data to stream reaches having similar characteristics; and provide a consistent frame of reference to aid communication of stream morphology and condition among workers from a variety of disciplines.

Central to the success of Rosgen's system in attaining the stated goals is the degree to which the delineative criteria for specific stream types actually fit the observed natural variation in river morphology. While Rosgen developed his system from a database of 450 rivers throughout the U.S., Canada, and New Zealand, it is new enough to require independent validation of its applicability, and refinement of the expected ranges of variability within the delineative criteria for stream types, for specific regions. Rosgen (1996a, page 3-7) has acknowledged the need for refinement of the system, using the analogy of the USDA Soil Classification system, which is essentially under continual refinement and revision. Indeed, Rosgen revised the delineative ranges of sinuosity for four of the major stream types (C, D, DA, & F) between publication of the basic system (Rosgen, 1994) and subsequent release of an expanded treatment in book form (Rosgen, 1996a). A major aid to the further evaluation of the generality of Rosgen's system would be the publication of the original 450 site data set.

Bankfull Discharge
Indicators
Bankfull, as a linear collection of geomorphic indicators running relatively parallel to the trend in water surface elevation, is distinct at all sites. At most sites, the top of bank/floodplain break is a primary indicator, with other indicators, depending on site-specific characteristics of the channels, present at the corresponding height above water surface. For instance, while the primary indicator along a reach might be the floodplain break, at locations where the channel is impinged on a terrace or hill-slope, a scour line (usually not continuous) composed of wear marks, undercuts, or obtuse slope breaks may be evident at the same elevation relative to water surface. At such points along a reach, the top of bank occurs at a higher elevation than the floodplain break. In some locations, local bank-top topography is uneven due to non-continuous but natural flood levee deposits, tree throws, or scour from over-bank flows. Because of this, simply plotting elevations for top of bank results in a nonlinear collection of points. At locations with a high bank where the channel has widened in the past, there might also be a depositional bench, the top of which also corresponds to the floodplain and scour elevations. At sites with well-developed point bars, the top of the point bar might also occur at the same relative elevation above the water surface as the floodplain break. However, there are many instances, particularly in channels with low width/depth ratios, where the tops of point bars are well below the elevation of the floodplain break.

We consistently observed the six distinct geomorphic indicators of bankfull stage described under Methods during the field surveys (Figure 5). At 83% of the sites, the elevation of the floodplain break indicates, at some points along the reach, the bankfull stage. At 61% of the sites, the inflection point indicates bankfull stage, and at between 30 and 40% of the sites the top-of-bench, a scour line, or a slope break indicates bankfull stage. Top of point bar indicates bankfull stage at less than 10% of sites.

At 13 of the sites, there also occurs a relatively linear set of geomorphic indicators well down inside the channel. This is often observed as a narrow bench, supporting annual vegetation or even very young individuals of perennial species, or a scour line below which little or no annual

vegetation grows. This lower series of indicators, which we refer to as the "active channel", first described by Osterkamp and others (1982), later in Northern Virginia (Osterkamp et.al. 1984) and in the southern Piedmont by Kolberg (1989), is usually much more discontinuous than the higher floodplain or top of bank series. We also found that the *lower indicator* was inconsistent in the Piedmont survey. Where it was found, it did not provide a contiguous set of indicators in the majority of sites. The selection of the actual bankfull indicators is a result of a consistent set of indicators surveyed throughout the Maryland Piedmont physiographic region.
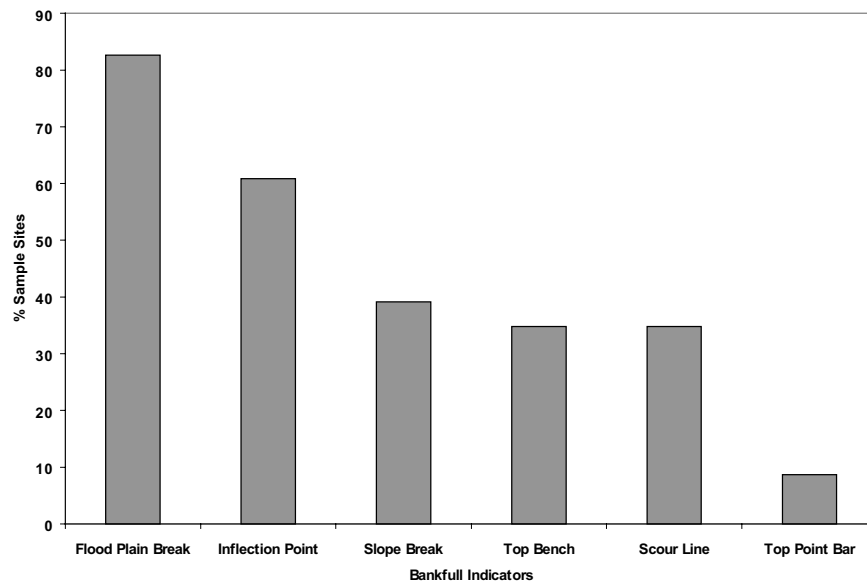
Figure 5. Percent of sites exhibiting geomorphic indicators of bankfull stage.
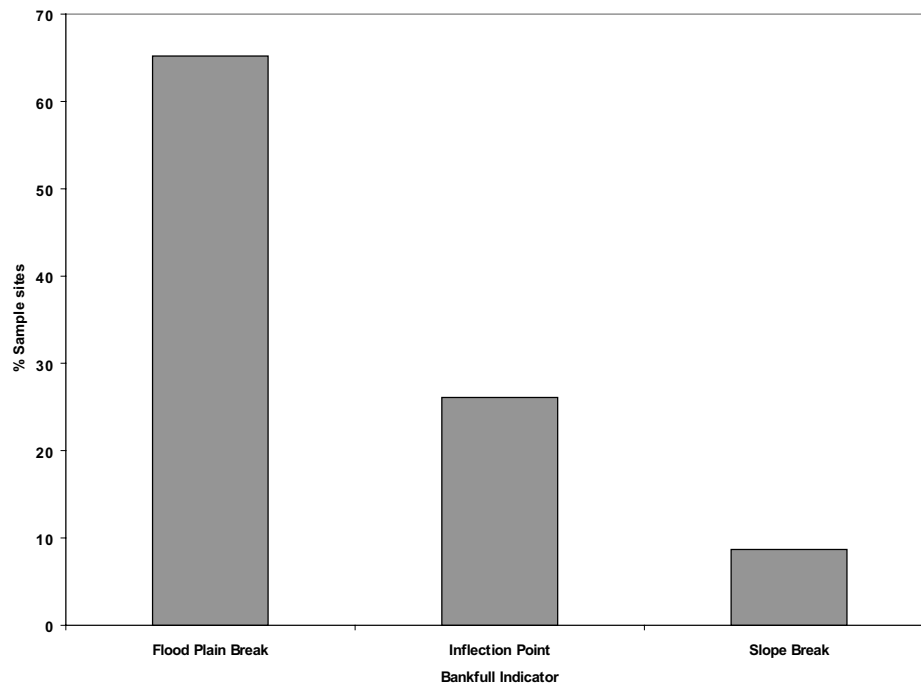
Figure 6. Percent of sites exhibiting primary bankfull indicators.

Discussion

A number of indicators for bankfull stage have been cited by many workers. These indicators include: the valley flat, the active floodplain, the low bench, the middle bench, the most prominent bench, tops of bars, the lower limit of perennial vegetation, the upper limit of sand in banks, the minimum width/depth ratio, the first maximum of the Riley bench index, a slope break in a plot of cross-sectional area vs. width, the 1.5 year recurrence interval discharge, the 1.58 year recurrence interval discharge, and the 2.33 year recurrence interval discharge. Williams (1978) compared the results of 16 published methods for estimating bankfull discharge applied to 28 different gaged sites in the western U. S., and documented a wide variability and lack of consistency in the magnitudes of the estimates, suggesting these indicators are not all related to the same flow, or narrow range of flows, within a reach. Williams also reiterated the problem of identifying some of the features, particularly the "active" floodplain, and the high degree of variability in others, such as vegetation and sediment size distribution. Williams concluded that investigators should specify the bankfull indicators used, and the way in which a corresponding discharge is determined for a chosen indicator. Our results strongly suggest that one indicator at all points along a reach does not mark the bankfull stage. Rather, while the floodplain break is the primary indicator, there exist additional secondary indicators such as scour marks and breaks in slope that occur at the same relative elevation.

Our observations also support those of previous workers who determined that vegetative patterns are best used to support a bankfull determination made based on geomorphic evidence. In the channels we surveyed, we often found large trees, particularly sycamores (*Platanus occidentialis*), growing well below the bankfull stage. In some cases, this was clearly due to slumping of the tree's root mass following erosion of supporting bank materials. While smaller individuals, presumably not more than one or two years, did seem to have a lower distributional limit near the geomorphic bankfull elevation, there was noticeably greater variation than for the geomorphic indicators.

Bankfull Discharge
By Drainage Area
Bankfull discharge is significantly related to drainage area, with about 93% of the variability in discharge explained by drainage area (Table V, Figure 7). Examination of Figure 7 reveals that four locations in the northeastern Piedmont region (Basin Run, Big Elk Creek, Northeast Creek, and Winters Run) plot relatively high, indicating a greater bankfull discharge per drainage area. However, Deer Creek, also in the northeastern Piedmont, plots on the trendline.

Table V. **Bankfull discharge vs. drainage area.** Bankfull discharge (cfs) regressed against drainage area (mi^2) for study reaches at USGS gage stations in the Maryland Piedmont. Calculated test statistics (F, se, t), degrees of freedom (df), significance (p), and coefficient of determination (R^2) for least-squares linear regression, and t-tests for differences between slopes and intercepts. NS = no significant difference at $\propto = 0.05$. All = data from all sample sites, NEP = data from northeastern Piedmont, MP = data from main Piedmont excluding NEP.

Group	N	Equation	R^2	Se (%)	F	p	df	t	p	df	t	p
								Slope			Intercept	
All	23	$Q_{bkf} = 84.56DA^{0.76}$	0.93	11	277	<.001						
NEP	5	$Q_{bkf} = 266.26DA^{0.52}$	0.98	4.5	117	<.001	19	4.04	.05	20	5.06	<.05
MP	17	$Q_{bkf} = 71.74DA^{0.78}$	0.98	5.8	882	<.001						
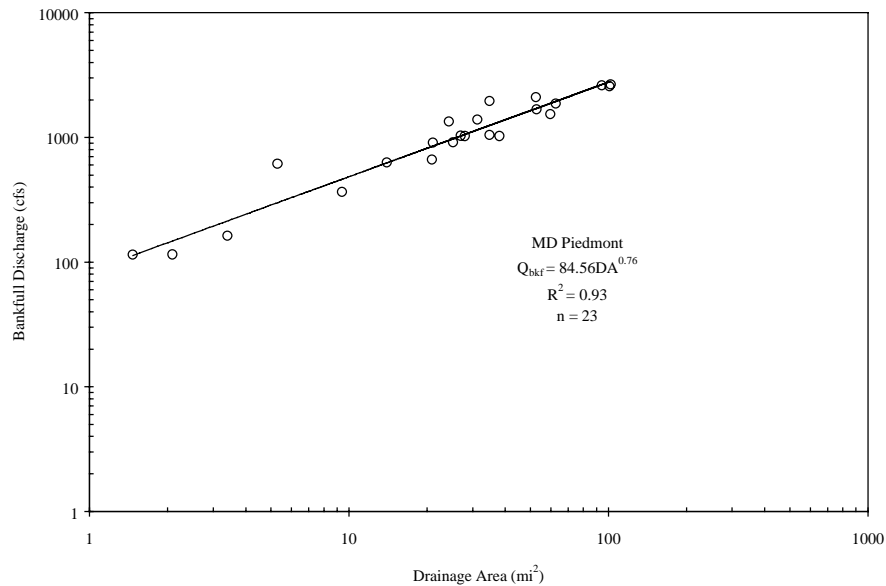
Figure 7. Bankfull discharge as a function of drainage area for Maryland Piedmont survey sites.
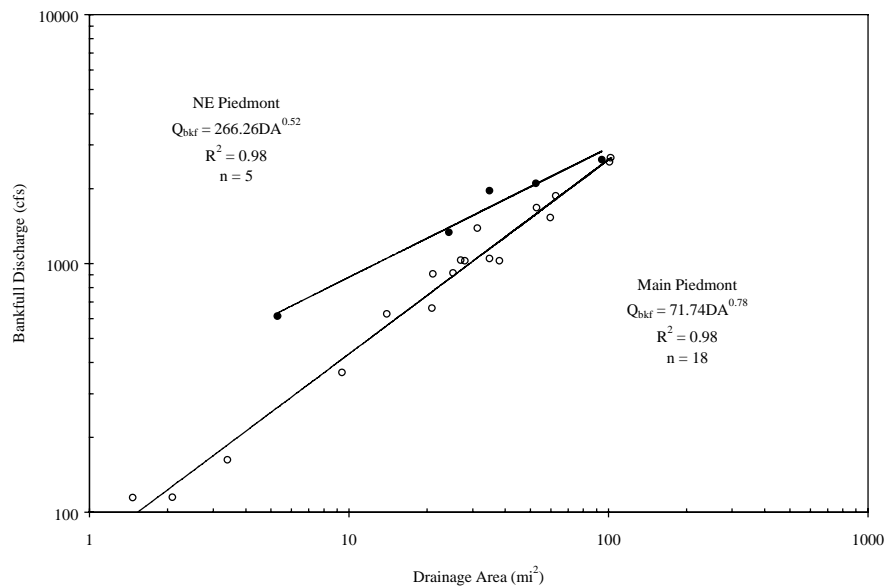
Figure 8. Bankfull discharge as a function of drainage area for Maryland Piedmont survey sites partitioned by northeastern Piedmont.

Partitioning the sites into groups composed of northeastern and main Piedmont sites results in significant relationships for both (Figure 8, Table V). The explanatory ability of the regression relationship for both the northeastern Piedmont and main Piedmont is improved somewhat over that of the full 23 sites. Comparison of the two regressions reveals they are significantly different, suggesting that streams in the northeastern Piedmont have a greater bankfull discharge per unit drainage area than streams in the remainder of Maryland's Piedmont region. The

relative change in discharge with a change in drainage area is different in the two regions as suggested by the differing slopes.

Discussion

The relationship between drainage area and bankfull discharge estimated for the Maryland Piedmont survey (Figure 7) compares well with those described from previous studies in the East (Table VI). In particular, those equations developed for Maryland and Pennsylvania (this study; Leopold and others, 1964; and Wolman & Leopold, 1957) describe relationships between drainage area and discharge that produce very close estimates. For 10 mi^2, these three equations predict discharges within a range of 147 cfs, representing approximately a 30% error, while for 100 mi^2, the range is 161 cfs and the error approximately 6%.

Table VI. Comparison of bankfull discharge to drainage area relationships from the Maryland Piedmont and other nearby regions. The relationships are all expressed as power functions of the form $Q_{bkf} = aDA^b$, where Qbkf is bankfull discharge in cubic feet per second and DA is drainage area in square miles. R^2 is the regression coefficient of determination, n = number of observations.					
Source	**a**	**b**	**n**	**R^2**	**Geographic Area**
This Study	84.56	0.76	23	0.93	Maryland Piedmont
This Study	71.74	0.78	18	0.98	Main Maryland Piedmont
This Study	266.26	0.52	5	0.98	NE Maryland Piedmont
Leopold et al., 1964	61	0.82	8	?	SE PA Piedmont
Wolman & Leopold, 1957	43.8	0.89	18	0.64	SC, NC, Maryland, PA, NY, CT
Brush, 1961	55	0.86	7	0.86	Central PA Valley & Ridge
Kilpatrick & Barnes, 1964	285	0.50	34	0.63	NC & SC, GA, AL Piedmont

The relationships for the NE Piedmont of Maryland and the Southern Piedmont between North Carolina and Alabama are strikingly different from the others. For the NE Piedmont, the greater bankfull discharge per drainage area may be partially due to a combination of greater runoff and bankfull recurrence intervals for that region. Two-year recurrence interval discharges from the USGS log-Pearson flood frequency distribution, which provide a measure of runoff magnitude independent of this survey, are greater in the NE Piedmont (Figure 9), compared to the rest of the region. Recurrence intervals, while not statistically greater in the northeast, nevertheless are mostly at the higher end of the range.

The high discharges estimated for the Piedmont in the southeastern states may be a consequence of both higher precipitation, and the definition of bankfull. Kilpatrick and Barnes (1964) defined bankfull as the elevation of the "primary", or widest, bench on the valley flat. In their study, of the data from sites where multiple benches were identified, the recurrence intervals for bankfull discharges corresponding to the primary benches ranged from 1.1 – 14.0 years, suggesting that infrequently flooded terraces may have been mistaken for active floodplains. Piedmont valleys experienced significant aggradation during early colonial era land clearing and pre-soil conservation agricultural practices (Trimble, 1974; Costa, 1975; Jacobsen & Coleman, 1986). Subsequent incision following decreases in sediment production has produced incised channels in many parts of the Piedmont with poorly defined active floodplains at lower relative elevations than the abandoned floodplains, or terraces, comprising most of the valley flats.
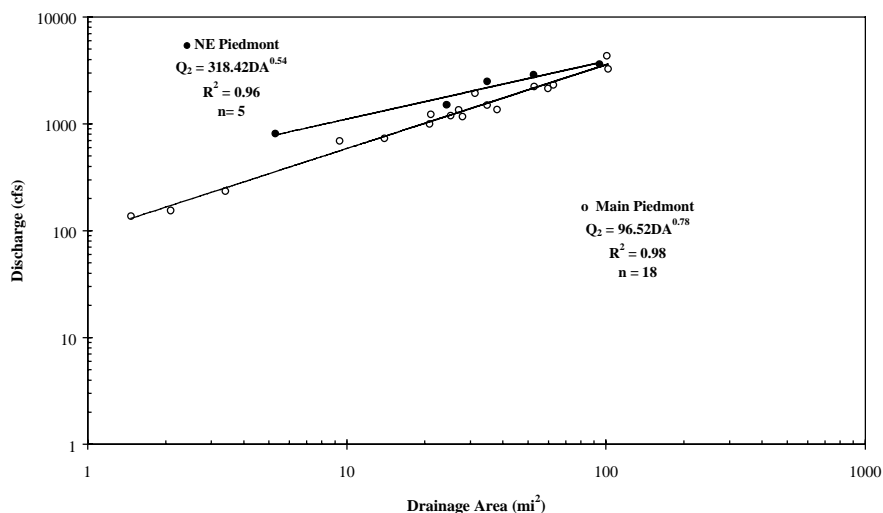
Figure 9. Two-year recurrence interval discharge as a function of drainage area, partitioned by northeastern Piedmont and the main Piedmont survey sites.

While the statistical analysis indicates that the bankfull discharge and drainage area relationship may be different for the northeastern Piedmont, our confidence in the results is low due to the low power associated with a small sample size for that sub-region. Although, the independent review of discharge strictly associated with the flood frequency data does support our observations, review of the northeastern Piedmont data set shows that the smallest site, Basin Run at Liberty Grove (an inactive site), has a large influence on the regression. Removing this site would result in a different trend line for the northeastern Piedmont. We think that additional survey work should be conducted in the northeastern Piedmont to not only examine the interaction of drainage area and bankfull discharge but also bankfull channel dimensions and drainage area. For this reason, we adopt a conservative approach below, and do not partition the various relationships by sub-region.

Although additional active gage sites were not available at the time of the survey in the northeast Piedmont, it would be interesting to plot channel dimensions for ungaged sites with the data of this study to see if the additional observations support the trend toward greater discharge. A second, process-based expectation is that the greater bankfull discharge per unit drainage area in the northeastern Piedmont would result in larger channels. However, to some extent it appears that larger discharges are accommodated by increased velocities in the northeastern Piedmont (Figure 10). Comparison of the average velocities (calculated using the continuity equation) at each site indicates that the northeastern Piedmont reaches tend to have velocities at the high end of the range observed for the 23 sites, with 3 of the 5 sites having higher reach average water surface slopes (Figure 11).
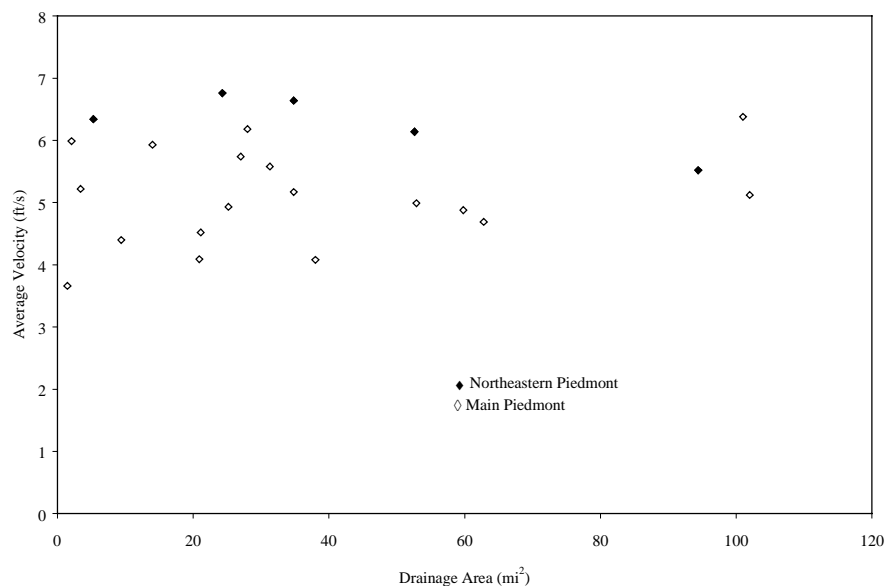
Figure 10. Average bankfull velocity for Piedmont survey sites.
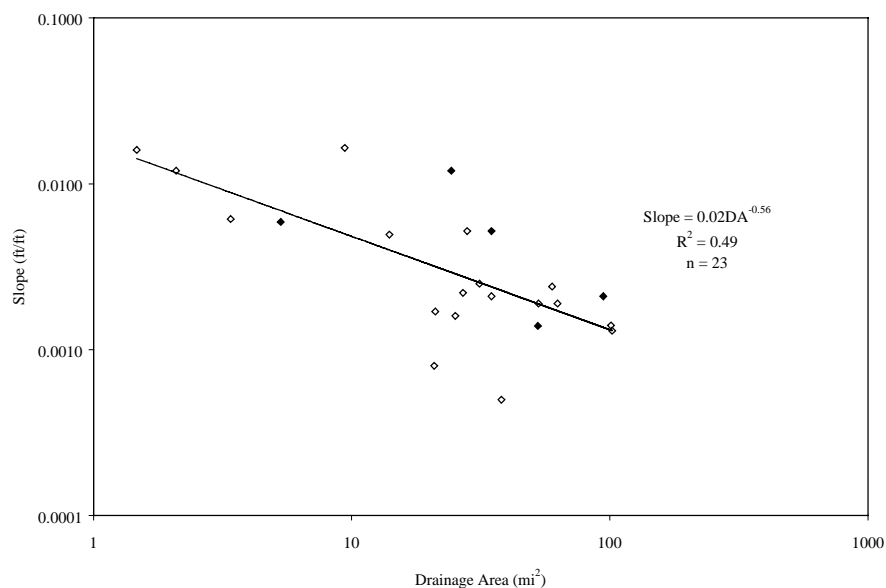
Figure 11. Reach average water surface slope as a function of drainage area (northeastern Piedmont sites shown as solid triangles).

Bankfull Discharge
Recurrence Interval
Recurrence intervals for field-estimated bankfull discharges, calculated from the annual maximum discharge series following the *Guidelines for Determining Flood Flow Frequency* (Interagency Advisory Committee, 1982), range from 1.26 – 1.75 years, and average 1.5 years (Figure 12). For several sites, the log-Pearson flood frequency did not match the period of record for the gage station. For example, at Seneca Creek and Jones Falls, we used later portions of the period of record for the flood frequency distribution to avoid problems associated with

significant changes in development. For both sites we examined the record of peak flows above base for obvious changes in magnitude of flows, and selected a cut-off date that excluded markedly lower flows and any obvious transition period. The log-Pearson period of analysis for each site is found in Appendix A.
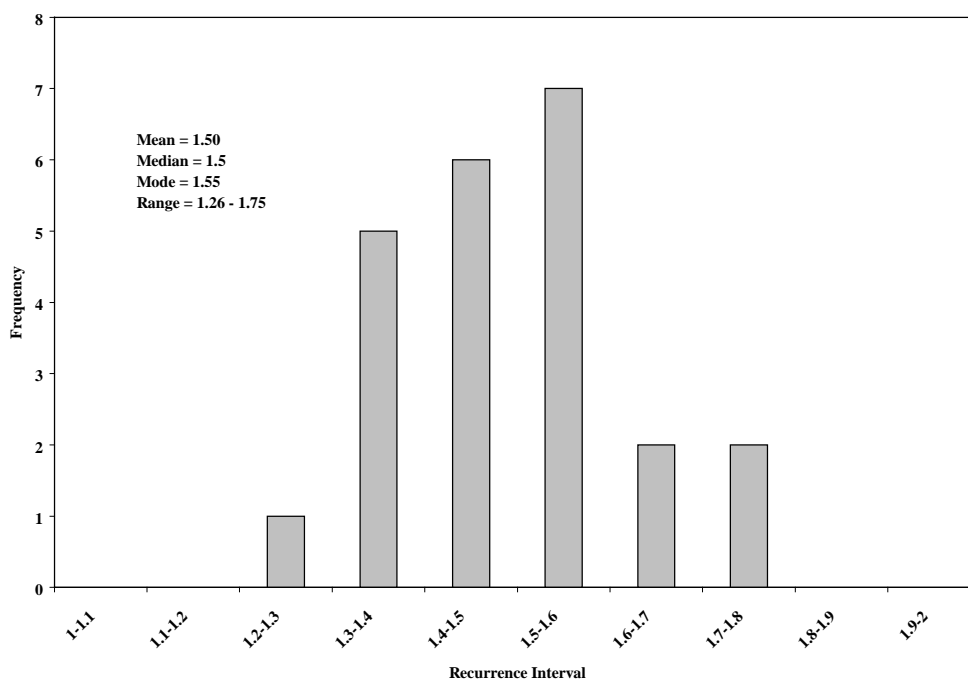
Figure 12. Frequency of recurrence interval for field-estimated bankfull discharge.
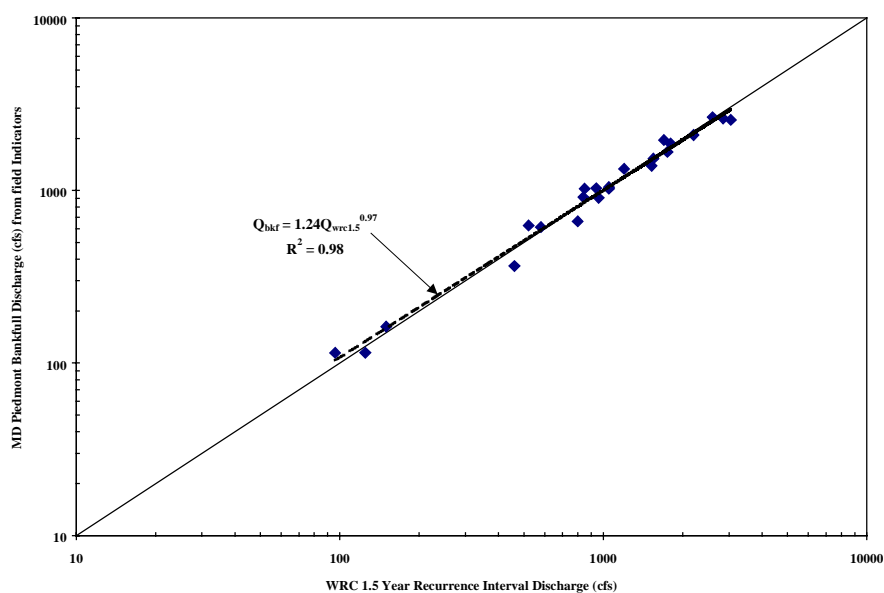
Figure 13. Comparison of field-estimated bankfull discharges from Maryland Piedmont survey sites with the WRC 1.5 recurrence intervals.

Comparison of the field-estimated bankfull discharges with the WRC 1.5-year recurrence intervals shows very close correspondence and a close fit to a 1:1 relationship (Figure 13). The average ratios of bankfull discharge to the WRC 1.5 and 2-year recurrence interval discharges are 1.01 (sd = 0.12) and 0.75 (sd = 0.08), respectively. Comparison of the regression relationships by drainage area for the field-estimated bankfull and WRC estimated 1.5-year recurrence interval discharges (Figure 14) reveals no difference in either the intercepts (t = -0.855, v = 42, p > 0.05) or slopes (t = -0.193, v = 43, p > 0.05). This indicates that the overall relationships between drainage area and the field estimated bankfull and 1.5-year recurrence interval discharges are essentially the same.

At 12 of the 13 sites where we observed a lower series of channel indicators, we extended the surveyed series through the gage to estimate a discharge. This lower series of geomorphic indicators is associated with a discharge close to the 1-year recurrence interval. The average recurrence interval is 1.07 years, with a standard deviation of 0.084, and a range of less than 1.005 to 1.2. A proportional frequency distribution shows that at half the sites, the recurrence interval of the low indicator is less than 1.01 years (Figure 15).
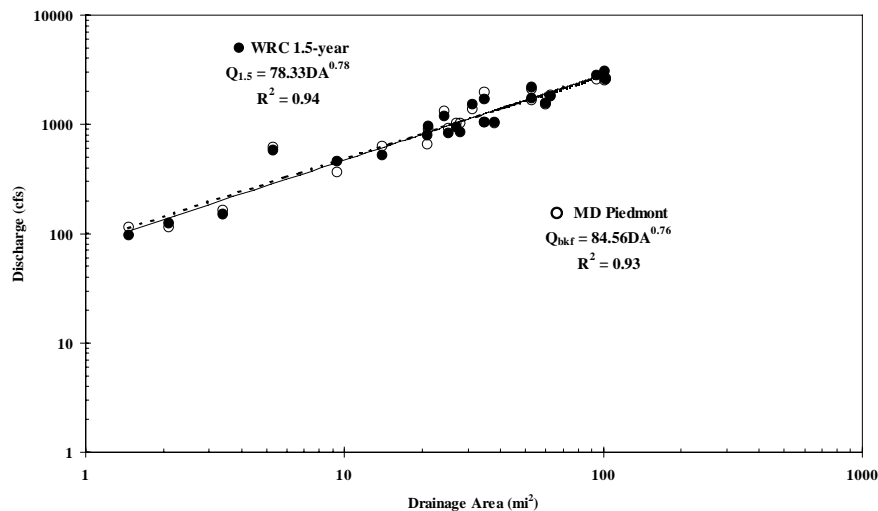
Figure 14. Drainage area versus discharge: Maryland Piedmont field-determined bankfull and WRC 1.5-year recurrence interval.
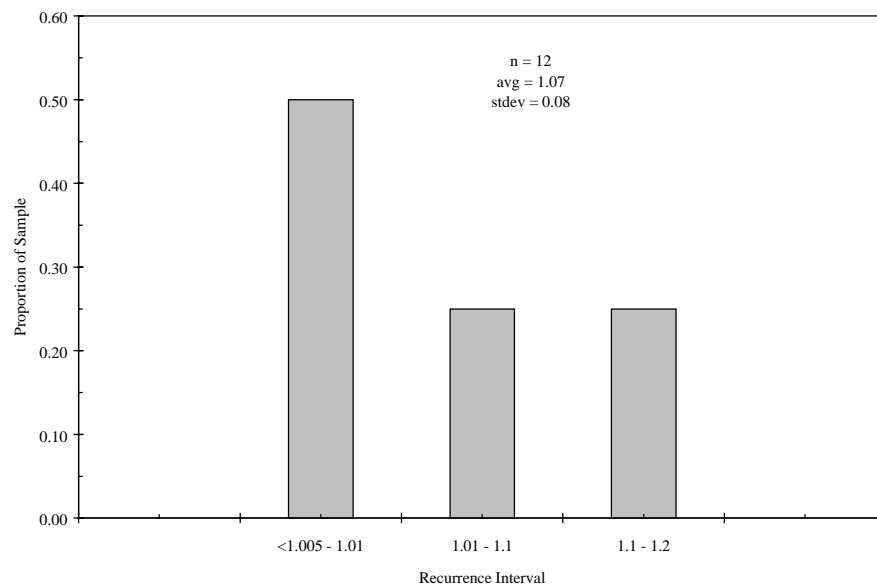
Figure 15. Recurrence intervals for field-observed active channel or inner berm.

Discussion

The recurrence intervals for discharges corresponding to the field-identified bankfull stages agreed well with previous work that has demonstrated a central tendency of 1.5 years on the annual maximum series. Wolman and Leopold (1957) reported bankfull recurrence intervals between 1 - 2 years for 37 reaches in the U.S. and India, and that at the "better studied" sites it was closer to 1 year. Although the range of bankfull recurrence interval estimate was from 1.01 to 200 years, Wolman and Leopold (1957) indicated that many of the sites with longer recurrence intervals occurred in steep, mountainous terrain with difficult to distinguish floodplains. For the 26 sites at which they considered the floodplain evident, the average recurrence interval was 1.59 years, with a range of 1.01 to 5 years. A frequency distribution of the recurrence intervals at these 26 sites indicates that at 54% of the sites the floodplain recurrence interval was between 1.01 and 1.2 years, between 1.2 and 1.6 years at 31%, and over 2 years at 15%. Interestingly, 8 of their 26 distinguishable floodplain sites were in the Piedmont physiographic region of Maryland and Pennsylvania. At these Piedmont sites, the average recurrence interval was 1.55 years, with a range of 1.07 to 2.7 years.

In addition to testing the correspondence of various bankfull indicators, Williams (1978) also examined the frequency distribution of bankfull discharge recurrence intervals for a compiled data set of 36 sites. Although the data came from several different workers, at all 36 sites bankfull was equated with the "active floodplain". The mode of the frequency distribution was approximately 1.5 years, with a range of 1.01 – 32 years. Similar to the data set of Wolman and Leopold, Williams reported data for several sites in the Eastern U.S. (Pennsylvania 3, West Virginia 2, Kentucky 2, and Tennessee 1). At these 8 sites, bankfull, which was equated to the elevation of the valley flat, averaged 28.4 years. However, all of the sites had recurrence intervals less than 2 years except for two sites with intervals of 3.4 and 200 years, respectively. Omitting the 200-year site, the average dropped to 1.56, with a range of 1.02 to 3.4 years.

Two other studies have examined bankfull discharge and recurrence intervals in the eastern U.S., and deserve comment. Kilpatrick and Barnes (1964) surveyed 34 sites in the Piedmont region of North Carolina, South Carolina, Georgia, and Alabama, using the most prominent bench as the indicator for bankfull. At four sites, it was not possible to distinguish between two bench levels regarding prominence. Using the higher of the two benches at these four sites, the average recurrence interval for the 34 sites was 3.68 years with a range of 1.01 – 14 years. Using the lower bench at the four sites, the average for the 34 sites was 3.4 years, with a range of 13.7 years. At 19 of the sites, multiple cross-sections were surveyed in a reach, permitting the detection of several benches. Five sites had two benches, eight sites had three benches, and five sites had four benches. Several aspects of the study make comparison with the others summarized above difficult. First, none of the benches were identified as active floodplain; second, the number of distinct benches at several sites suggests that incision and floodplain abandonment may have occurred; and third, significant changes in channel slope were present in many of the reaches.

Brush (1961) examined relationships between drainage area and bankfull discharge at 119 reaches on 16 streams in central Pennsylvania. None of the reaches was gaged, but at five gage sites in the vicinity, Brush surveyed the bankfull (not defined specifically, but assumed to equal top of bank) channel and determined that the recurrence intervals ranged from 1.9 to 10 years on the partial duration series. By plotting specific recurrence interval discharges against drainage area for the five stations, and comparing the resulting iso-frequency lines to the plotted bankfull discharges by drainage area, Brush determined that the mean annual flood (recurrence interval = 2.33 years) line best fit the measured bankfull points. On this basis, he concluded that bankfull discharge at the 119 stations was equivalent to the mean annual discharge. This approach to determining bankfull discharge is significantly different from the present study or the others summarized, in which longitudinal profiles were surveyed through active gaging stations. Also, as in the Kilpatrick and Barnes study, there was no evaluation of whether the top of bank was likely the active floodplain, or even if the top of bank elevations paralleled water surface, as would be expected for a channel maintaining flow.

Thus, the previous studies (Wolman & Leopold, 1957; Williams, 1978) that involved methods and geographic locations similar to that used in the present study reported recurrence intervals very similar to those we estimated in the Maryland Piedmont. At this point in time, and with the available information, it is difficult to address the greater ranges of bankfull recurrence intervals reported in the earlier studies. It is apparent; however, those differing definitions of bankfull and methods of estimation may likely contribute greatly to these discrepancies.

Comparison of Gage and Study Reaches
At 20 sites, the gage and study reaches are located some distance apart, raising the possibility that bankfull dimensions at the study reaches are not indicative of the discharges measured at the gages. To test the hypothesis that the bankfull channels we measured at the study reaches are not likely associated with the bankfull discharges we estimated at the gage reach, we compared the cross-sectional areas for each. In all cases, the indicators we used to delineate the bankfull channel in the gage reach were the same as the study reach. Our assumption is that, with no major tributaries in between, the range of discharges that forms and maintains the channel at the gage is also responsible for channel dimensions in the nearby study reach. Channel cross-sectional area near the gage is plotted against cross-sectional area in the study reaches in Figure

16, along with the line representing a 1:1 correspondence for comparison. A paired t-test detects no difference in the mean cross-sectional areas of the two reaches (Gage cross-section mean = 237 ± 34; Study reach cross section mean = 230 ± 34; t = 1.4, df = 19). Thus, we conclude that the bankfull channels identified in the study reaches are likely the result of the same range of discharges forming and maintaining the bankfull channels in the gage reaches.
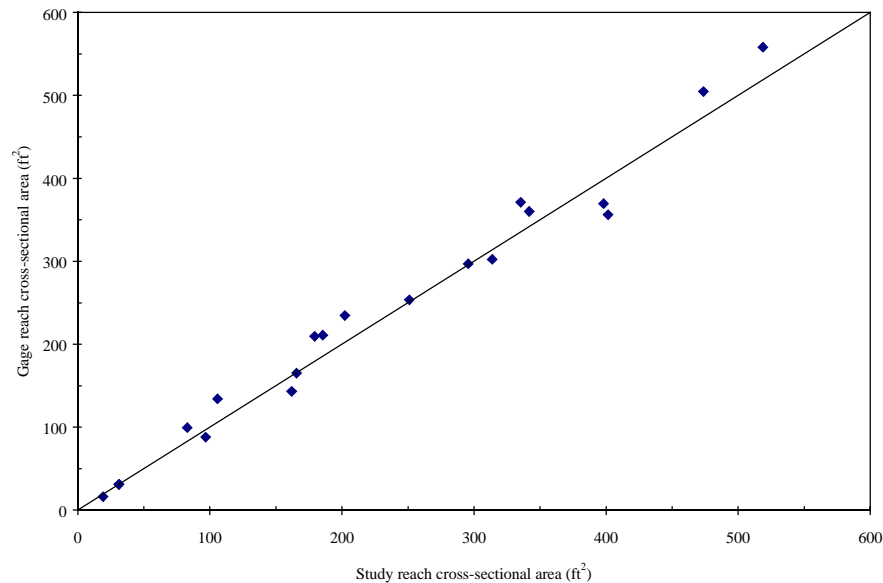
Figure 16. Comparison of gage reach and study reach cross-sectional area.

Cross-section Relationships
We used data from the cross-section surveys to test for predictive relationships between the independent variables of drainage area and bankfull discharge and the dependent variables of width, mean depth, and cross-sectional area. We also tested for relationships between bank material composition and channel shape, and between relative roughness (R/D84) and flow resistance (Manning's "n").

By Drainage Area
We used data from the cross-section surveys to test for predictive relationships for width, mean depth, and cross-sectional area. Width, mean depth, and cross-sectional area are all significantly related to drainage area (Figure 17, Table VII). Of the three parameters, cross-sectional area has the greatest percent of the variability in size explained by drainage area, followed by mean depth and width, as indicated by the regression coefficients of determination (R^2 values).

Table VII. Cross-section dimensions vs. drainage area. Bankfull width (ft), mean depth (ft), and cross-sectional area (ft^2) regressed against drainage area (mi^2) for study reaches at USGS gage stations in the Maryland Piedmont. Calculated test statistics (F, se), significance (p), and coefficient of determination (R^2) for least-squares linear regression.					
N	**Regression Equation**	**R^2**	**Se (%)**	**F**	**p**
23	Cross-sectional Area = $17.42DA^{0.73}$	0.95	9.1	368.7	<.001
23	Width = $14.78DA^{0.39}$	0.83	9.1	104.3	<.001
23	Depth = $1.18DA^{0.34}$	0.86	6.5	160.7	<.001
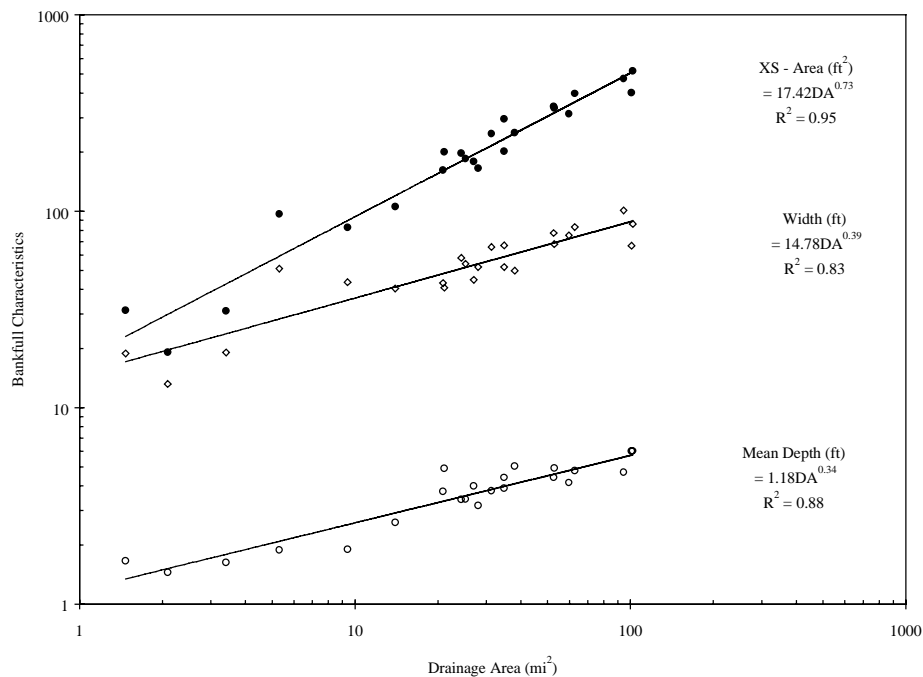
Figure 17. Bankfull channel dimensions as a function of drainage area for Maryland Piedmont survey sites (n = 23).

Discussion

The results of this study document significant relationships between all three cross-section parameters (area, width, and depth) and drainage area in streams of the Maryland Piedmont. Cross-sectional area is the parameter for which drainage area explains most of the observed variability, followed in order by depth and width.

Currently, the graphical relationships between drainage area and bankfull channel dimensions in southeastern Pennsylvania, published by Leopold and his co-workers (Leopold et al., 1964; Dunne & Leopold, 1978), are used by many environmental scientists and engineers for predicting bankfull dimensions at ungaged stream reaches in the Piedmont region of Virginia, Maryland, and Pennsylvania. Unfortunately, neither of these two references provide either equations or data for the relationships. We have estimated the equations for the published regression lines by graphically identifying points along the lines that coincide with intersections of iso-values of drainage area and dimensions. These estimated equations, expressed as power functions are $A = 20.5DA^{0.71}$, $W = 14.3DA^{0.39}$, and $D = 1.4DA^{0.3}$. As with the relationships between drainage area and bankfull discharge reviewed above, comparison of these equations with the power functions summarized in Figure 17 reveals an extremely close correspondence between the southeastern Pennsylvania regression relationships and those developed in this study for the Maryland Piedmont.

By Bankfull Discharge

Width, mean depth, and cross-sectional area in the Piedmont streams are all significantly related to bankfull discharge (Figure 18). Comparison of the coefficients of determination (R^2) show that, as with drainage area, discharge best explains the variability in cross-sectional area, followed in order by width and depth (Table VIII).

N	Regression Equation	R^2	Se (%)	F	p
\multicolumn{6}{c}{**Table VIII. Cross-section dimensions vs. bankfull discharge.** Bankfull width (ft), mean depth (ft), and cross-sectional area (ft^2) regressed against bankfull discharge (cfs) for study reaches at USGS gage stations in the Maryland Piedmont. Calculated test statistics (F, se), significance (p), and coefficient of determination (R^2) for least-squares linear regression.}
23	Cross-sectional Area = $0.28Q_{bkf}^{0.94}$	0.97	6.8	629.1	<.001
23	Width = $1.46Q_{bkf}^{0.52}$	0.92	6.5	228	<.001
23	Depth = $0.19Q_{bkf}^{0.42}$	0.83	7.9	102.5	<.001
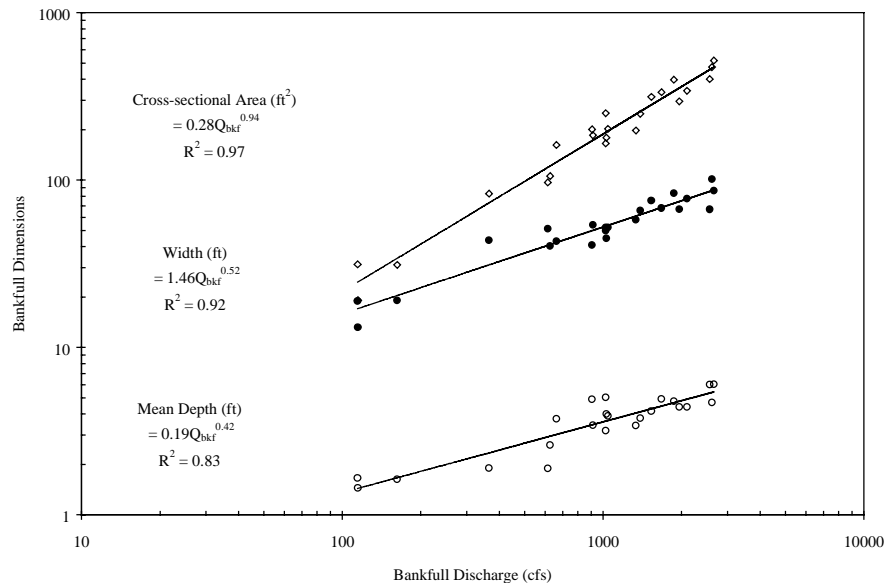
Figure 18. Bankfull channel dimensions as a function of bankfull discharge for Maryland Piedmont surveys sites (n = 23).

Discussion

The power function equations determined in this study compare favorably with the equations developed by other workers (Table IX). This is particularly true for the exponents (b), which describe the slope of the regression line, and indicate the degree of change in a dimensional parameter for every unit of change in bankfull discharge. As for the relationships observed between cross-section dimensions and drainage area, the exponents for cross-sectional area vary the least among the studies, again indicating that cross-sectional area, which represents a dynamic balance between width and depth, is a more conservative parameter than either width or depth alone. Neither Leopold & Maddock (1953) nor Wolman (1955) provided coefficients for the relationships determined in their studies. The equations of this study and that of Nixon

(1959) have dimensional units in feet, while that of Hey and Thorne (1986) is for metric units. One may compare the slope functions expressed by the dimensionless exponents directly, however the coefficients, which represent the y intercepts, must be converted for comparison. The converted (to feet) coefficient ranges provided by Hey and Thorne for width (7.12-13.06) and depth (0.52-0.65) suggest their study streams have greater width/depth ratios than those of this study and that of Nixon.

Table IX. Comparison of relationships between bankfull discharge and channel dimensions. Coefficients and exponents of power functions describing relationships between bankfull discharge and channel dimensions from selected channel geometry studies. Power functions have the form $W = aQ_{bkf}^{b}$, $D = cQ_{bkf}^{f}$ and $A = gQ_{bkf}^{h}$. Superscripts: for Study, 1 = units in feet, 2 = metric; for Area, * = determined by regression analysis, + = determined from mathematical relationship of hydraulic geometry equations wherein h=b+f. Hey & Thorne provide separate equations for different bank vegetation conditions, hence the range of coefficients.

Study	Width (W)		Depth (D)		Area (A)	
	a	b	c	f	g	h
This Study[1]	1.46	0.52	0.19	0.42	0.28	0.94
Leopold & Maddock, 1953-2[1]		0.50		0.40		0.90[+]
Hey & Thorne, 1978[2]	2.17-3.98	0.52	0.16-0.20	0.39		0.91[+]
Nixon, 1959[1]	1.65	0.50	0.55	0.33	0.9	0.83
Wolman, 1955[1]		0.42		0.45		0.87[+]

Cross-section shape

There is not a significant relationship (Table XI) between channel shape, as described by the width/depth (W/d) ratio, and the percentage of bank materials composed of silt and clay, indicating that other factors play a stronger controlling role in the channel shape. The sample size for the analysis of w/d ratios as a function of silt-clay content is 22, rather than 23 sites, because Northeast Creek has cobble and boulder banks with only a thin mantle of finer sediment and is not included in the analysis.

Table XI. Channel shape (width/depth) vs. stream bank silt-clay content. Bankfull width/depth ratio of classification cross-section regressed against % silt-clay in bank sediments for study reaches at USGS gage stations in Maryland Piedmont. Calculated test statistics (F, se), significance (p), and coefficient of determination (R^2) for least-squares linear regression.

N	Regression Equation	R^2	Se (%)	F	p
22	W/D = -0.17(%Silt-Clay) + 18.52	0.13	446	2.96	NS

Discussion

Schumm (1960) reported a significant and negative relationship between bank silt-clay content and width/depth ratio for 69 streams in the mid-west using a weighted mean percent silt-clay content for the channel perimeter as a whole, based on bulk samples of both bed and bank materials. We did not collect bulk samples of bed materials, precluding a strict comparison with Schumm's findings. Bank silt-clay content ranges from about 5% to 45% by dry weight among the 23 Piedmont sites sampled. A plot (Figure 19) of the Piedmont data with Schumm's data for 19 sites with a comparable range of bank silt-clay content shows an almost complete separation of the two data sets. For any silt-clay content in this range, Piedmont streams have average lower width/depth ratios.
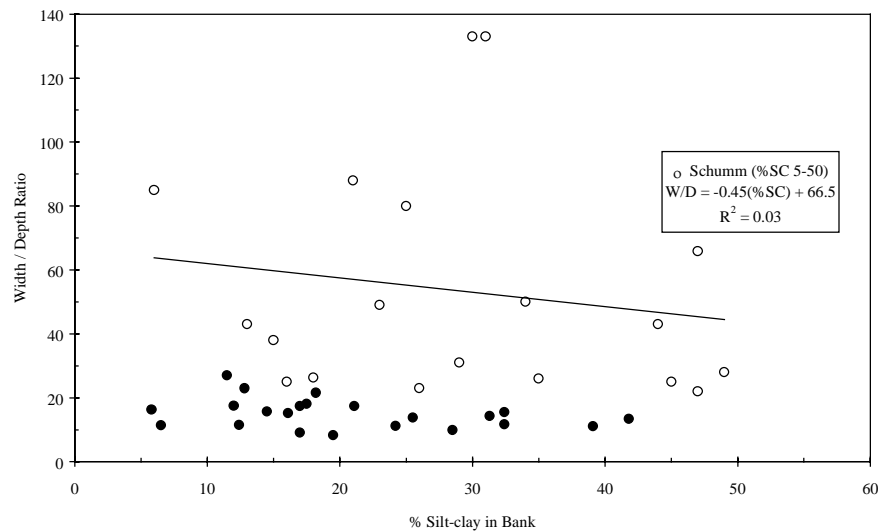
Figure 19. Channel form (width/depth) as a function of bank silt-clay content. Maryland Piedmont data (shown as solid dots) compared with Schumm (1960).

Resistance Relationships

There is a significant relationship between relative roughness (R/D_{84}), and resistance expressed as Manning's "n", with about 75% of the variability in n values explained by the relative roughness of the bed material (Table XII, Figure 20). However, the derivation of both the dependent and independent variable includes the hydraulic radius.

N	Regression Equation	R^2	Se (%)	F	p
23	"n" = $0.062(R/D_{84})^{-0.20}$	0.75	0.7	44.4	<.001

Table XII. **Flow resistance as a function of relative roughness.** Average flow resistance expressed as Manning's "n", regressed against relative roughness, or R/D_{84}. Calculated test statistics (F, se), significance (p), and coefficient of determination (R^2) for least-squares linear regression.

Discussion

Comparison of the Maryland Piedmont data with the data of Limerinos (1970) from California (Figure 21) and with Hey's (1979) data from Britain (Figure 22) indicates a close correspondence in both cases. For ease of comparison, we have converted the Maryland "n" values to match Limerinos and Hey who express resistance as $n/R^{1/6}$ and as Darcy-Weisbach "f", respectively. To make the comparisons as meaningful as possible, only those sites that fell within the ranges reported by Limerinos and Hey for R, slope, D_{84}, and R/D_{84} were used in the regression analysis; the remaining sites that fell outside these ranges are shown for comparison.
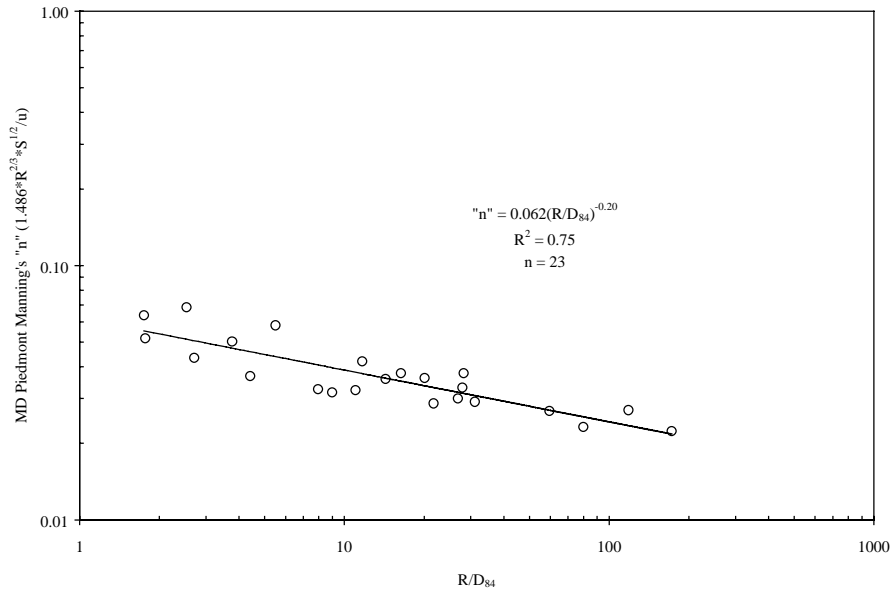
Figure 20. Manning's "n" as a function of relative roughness (R/D_{84}) for Maryland Piedmont survey sites.
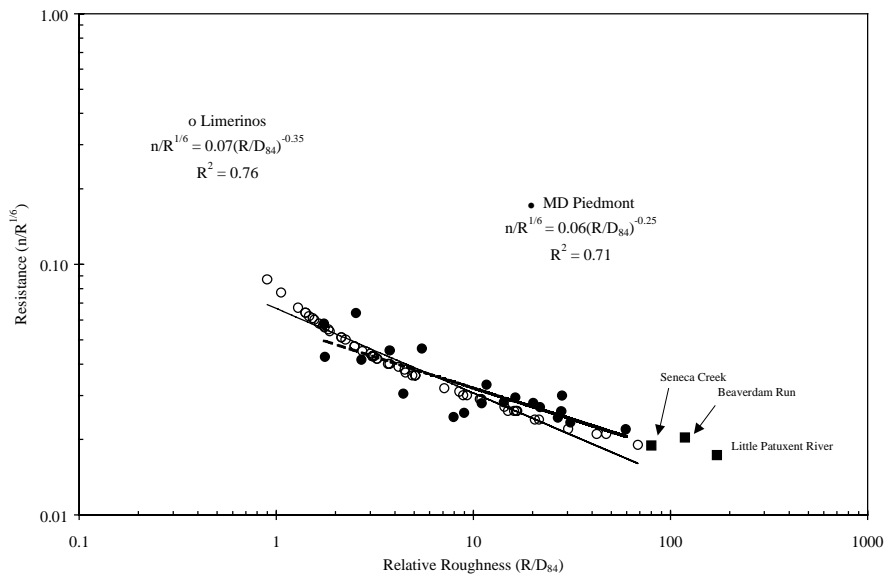
Figure 21. Manning's "n" as a function of relative roughness (R/D_{84}). Maryland Piedmont survey sites compared with Limerinos (1970). Maryland Piedmont samples outside range of Limerinos are labeled and not included in regression analysis.
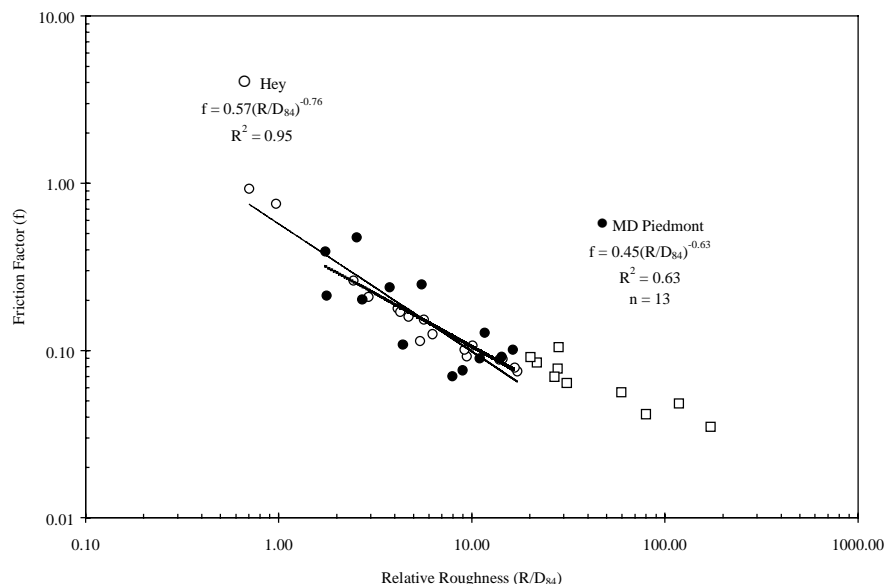
Figure 22. Friction factor as a function of relative roughness. Maryland Piedmont survey sites compared with Hey (1979). Square symbols represent Maryland Piedmont samples outside of Hey's data range and are not included in regression analysis.

<u>Resistance by Stream Type</u>

Rosgen (1994, 1996a) has published a summary of average "n" values by stream type. Because Rosgen did not publish the data, we have estimated the average values from his published figure, and plotted them in descending values of Manning's "n" for comparison with the Maryland Piedmont data for individual stream types and the average and range for groups of stream types (Figure 23). The single Piedmont observation for B4 (0.033) plots near the Rosgen average for this stream type, while the single E4 (0.043) plots slightly above the average values presented by Rosgen for E3/E4 stream types. While Rosgen does not provide values for C type streams with boulder and bedrock bed material, the Maryland Piedmont average (in parentheses, $\pm$ 1 sd) (0.058 $\pm$ 0.008) plot between B2 and B3 Rosgen stream types. The Piedmont averages for E5 (0.029 $\pm$ 0.009) stream types are very close to the average of E5/E6 stream types, C5 (0.026 $\pm$ 0.004) and C4 (0.038 $\pm$ 0.01) observations indicate a fair amount of variability, and significant divergence from the averages provided by Rosgen. A Mann – Whitney test detected a significant difference (p = 0.02) in "n" values among the C5 and C4 stream types in the Maryland Piedmont.

Rosgen has reported that most of the C4 streams in his data set were larger than the streams we surveyed in the Maryland Piedmont. In our surveyed streams, the combined mean depth for C4 stream types is 3.8 ft with an average "n" value of 0.038 (range 0.027 - 0.069). For C5 stream types the combined mean depth is 4.3 ft with an average "n" value of 0.025 (range 0.022 - 0.029). Upon review of the draft Maryland Piedmont report, Rosgen suggests that until more data are collected, an adjustment of the Manning's "n" values by stream type is warranted for C4 and C5 stream types in the Maryland Piedmont (written commun., 1999). For C4 and C5 streams with average depths less than 4 feet, use 0.038 for C4 and 0.025 for C5 streams. The influence of in-channel riparian vegetation and woody debris can obviously have a large effect on the predicted roughness value.
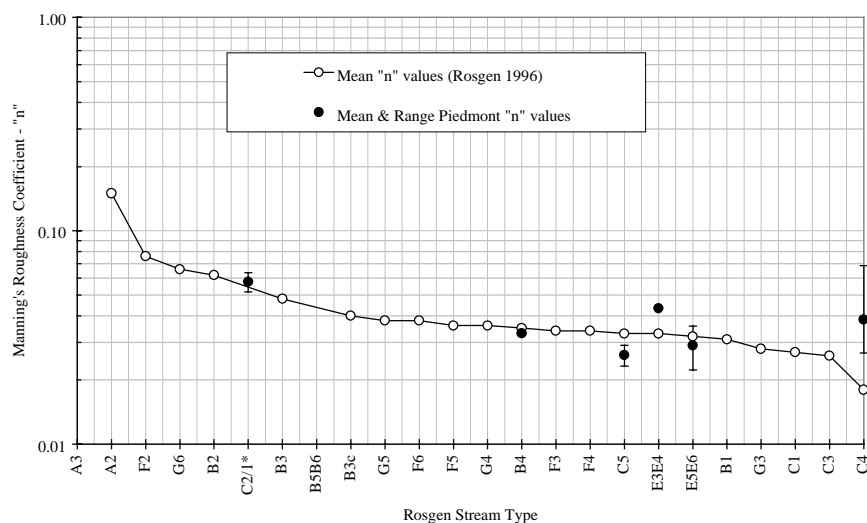
Figure 23. Comparison of Maryland Piedmont survey sites Manning's "n" values with average "n" values by Rosgen stream type (adapted from Rosgen 1996).

Shear Stress

For 23 sites, the calculated average boundary shear stress ($\tau_o = p_wgRS$) at the bankfull stage exceeds the estimated critical shear stress (τ_{cr}) for the D_{50} of the riffle bed material (Figure 24). We selected a value of 0.03 for the Shield's dimensionless parameter in the abscissa based on review of the literature and discussions with several experienced workers (G. Parker and W. Emmett, pers. comm.). Subsequently, we have been made aware of publications that suggest different, larger values would be more appropriate for the Shield's parameter (Buffington and Montgomery (1997) Wilcock (2001)). Nevertheless, in the absence of both empirical data required for estimating the Shield's parameter, and a clear rationale for selecting a specific value, we have elected to retain our original approach. The point of the exercise is simply to develop a coarse estimate of the degree to which the bed materials are likely to be subject to movement at or near the estimated bankfull stage. With these caveats, the comparison suggests that, for those sites plotting above the line of agreement, bed materials are likely mobile at or near the bankfull stage.

Discussion

Most of the study sites had calculated τ_o greater than the estimated τ_{cr} for the D_{50} of the bed material. The low site plotting closest to the line, Big Pipe Creek, appears altered upstream of the gage by channelization. The low τ_o for the observed particle size distribution may be an indication of an incipient shift in sediment transport dynamics at this site. The site plotting with the greatest τ_{cr} is Northeast Creek, has one of the steepest gradients of the 23 sites, 1.7%, and large bed material. The median particle diameter, or D_{50}, is 0.3 feet, while the D_{84} and D_{95} are 1 and 1.7 feet, respectively. Carling (1988) has shown that steep channels with large and armored bed material are susceptible to general mobilization of bed clasts only at flows that significantly exceed bankfull.
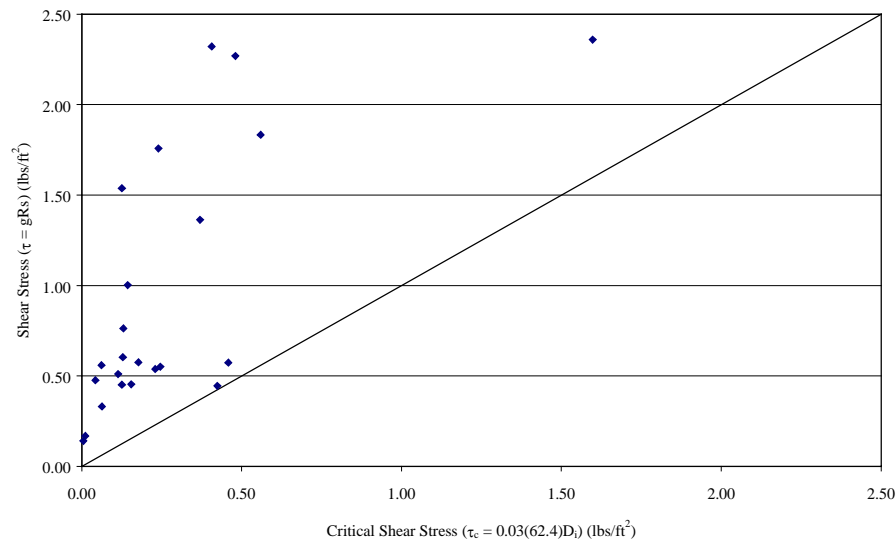
Figure 24. Comparison of estimated average boundary shear stress and calculated critical shear stress.

CONCLUSIONS

- Maryland Piedmont channels can be classified using the Rosgen stream classification system, however, the limited number of independent observations of different stream types at this point in the work prevents us from examining the use of the classification in helping explain some of the observed variability in stream characteristics.

- The northeastern Piedmont may constitute a discrete region with respect to the relationship between drainage area and bankfull discharge. However, more surveys are necessary for a proper statistical analysis.

- There is a well-defined relationship between drainage area and bankfull discharge in the main Piedmont region.

- There are well-defined relationships for Maryland Piedmont streams between drainage area and bankfull channel dimensions, and these relationships compare favorably to those documented by previous workers elsewhere in the Piedmont of the eastern U.S. and nearby regions. The most conservative relationship with drainage area is for cross-sectional area.

- Width/depth ratios are not significantly related to silt-clay content of banks. In general, for a given silt-clay content Piedmont streams have much lower width/depth ratios than the mid-west streams studied by Schumm (1960).

- Variability in the average flow resistance in Maryland Piedmont streams as represented by the Manning "n" is fairly well explained by variability in relative roughness, expressed as R/D_{84}.

APPLICATIONS
Use of Regression Relationships for Design Purposes
Several caveats exist for these relationships, and argue strongly against their use for detailed design specifications.

- Relationships are representative of a restricted range of basin and reach characteristics (e.g. drainage area, geology, land use, etc.) and must be used with caution when applying to streams across the Piedmont.

- Often the gage and study reaches are not the same reaches. Rather to maintain the study reach selection parameters, it is often located upstream of the gage.

- While we do not consider any of the reaches represented here to be in a state of rapid adjustment, we have no information about the relative rates of lateral or down-valley meander migration.

- Relationships are not necessarily representative of "reference reach conditions". We suspect that many reaches in proximity to gages at road crossings were altered at some time in the past by channelization or realignment. These relationships provide no information about ecological parameters, and may not represent "good" habitat conditions. In fact, the low amounts of large woody debris in the surveyed channels are likely an indication of relatively poor habitat conditions.

- Many of these reaches have significant bedrock controls such that general extrapolation of meander and profile patterns to situations lacking such bedrock influence may not be appropriate.

- The range of stream types represented by the data is low, with one to three streams observed in most stream types (B4, C5, C2, E5, and E4), and only C4 stream types well represented with fifteen observations. Several common stream types, such as A2 and B3, often found in geologically confined transitional reaches, are not represented.

- The reaches represented here seem to broadly correspond to the category termed "transport" reaches, in that well developed depositional features such as point bars are not well represented. Imposition of the channel characteristics represented by these relationships on streams in the "source" and "response" categories would likely be problematic.

Given these caveats, the relationships documented here can provide preliminary design parameters for streams with a similar range of discharge, sediment, slope, and entrenchment conditions. However, channel designers need to identify discrete project goals and objectives, with respect to both physical and biological desired conditions, and determine the appropriate design parameters for achieving those conditions. In most cases the best guidance for finer scale aspects of channel design will come from carefully selected reference reaches that closely match the controlling conditions at the project reach, and exhibit those characteristics specifically identified as design objectives. The results of this study may best serve as a guide to the expected range of dimensions for bankfull channels at ungaged reaches.

Recommendations for Phase II

For Phase II of the Maryland Stream Survey, we recommend modifications to channel surveys as follows:

- Surveys will be confined, as much as possible, to a single reach containing the gage, to avoid problems of extrapolation.

- Surveys will consist of longitudinal profiles and cross-sections, and not include meander geometry. This will narrow the focus of the study to relationships between drainage area and bankfull discharge and drainage area and bankfull cross-section. These relationships are intended for primary use as guides to preliminary identification of bankfull channel dimensions at ungaged reaches.

- Surveys will include stream classification, to broaden the base of information for the utility of the Rosgen classification system in partitioning the data.

Recommendations for Additional Surveys

- Once the gage calibration surveys represented by Phases I and II are in-hand, they can be used to facilitate the identification of bankfull channels at ungaged reference reaches selected for particular purposes including biological quality, sediment transport, over-bank discharge frequency, and diversity of fluvial features. This information will provide a foundation for future development of a reference reach database for Maryland streams.

- Surveys of additional sites in the northeastern Piedmont are needed. Although additional active gage sites are not available, discontinued stations with updated stage-discharge relationships would provide useful information regarding the magnitudes of bankfull discharge and channel dimensions.

- Additional observations of stream reaches, and reaches with less bedrock control and perhaps a greater range of bank material composition than was present in this set of study sites, will be necessary to test the ability of Rosgen's system to usefully partition channel types.

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APPENDIX A

Site Characteristics for Selected USGS Gage Stations in the Piedmont Physiographic Province

This Appendix provides summaries of field data collected by the U.S. Fish and Wildlife Service (Service) at twenty-three U.S. Geological Survey (USGS) gage station monitored stream sites in the Piedmont hydro-physiographic region of Maryland. Survey methods are presented in Appendix B *Protocols for field surveys at gage stations*.

Of the twenty-three sites surveyed, eighteen stations were active at the time of the survey. For three sites (Basin Run at Liberty Grove, Baisman Run at Broadmoor, Slade Run near Glyndon, and Northeast Creek at Leslie), the USGS revised the existing rating table prior to survey work. At most sites, a study reach was surveyed up- or downstream of the gage station to meet site selection criteria although in some cases, the gage reach is contained within the study reach.

For each site, information and survey data is summarized on four pages. The first page for each site contains general information on the drainage basin, gage station, and the study reach. The Maryland State Highway Administration provided land use/land cover information using the software program *GIS Hydro* (Ragan 1991) and 1994 Landsat and Spot coverages. Stream order and magnitude are based on Strahler (1964) and Shreve (1967), respectively. The reported discharge recurrence intervals are from the log-Pearson type III flood frequency distribution for the annual maximum series calculated by USGS according to the WRC Bulletin 17B procedures. The second page provides information on the study reach including cross-section plots and particle size distributions in the riffle and reach. The third page shows photographic views of the surveyed cross-section in the study reach and the fourth page provides a scale plan form diagram of the study reach mapped using a total station survey instrument and generated with the graphic and survey reduction software *Terra model*.

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Table of Contents

BAISMAN RUN AT BROADMOOR, MD
USGS STATION NUMBER: 1583580

Latitude:	39º 28' 45"	Gage Period of Record:	1964 – 1969
Longitude:	76º 40' 42"		1970 – 1976
ADC Map Coordinates:	Baltimore / 1993		1999 - Present
	Map 18 / C5	Mean Annual Discharge (cfs):	1.85
Drainage Area (sq. mi.):	1.47	Rosgen Stream Type:	C4
Stream Order / Magnitude:	2 / 2	Survey Date:	Oct. 1998
Percent Imperviousness:	4.25		

Land Use (%):   Residential: 16.98   Agricultural: 4.72   Forest: 75.47   Commercial: 0.00

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 4.8 (sys) $Q_{1.5}$: 96.00 $Q_{2.0}$: 136.70
(Log-Pearson Period: 1965 – 1976, 1999)

General Study Reach Description: The study reach and gage reach are the same and located at a temporary gage location downstream while the bridge was under construction. The reach has pool/riffle morphology, a regular meander pattern with minor depositional features and some lateral scour, and appears vertically stable. The upstream end of the reach is ditched, and the lower end lies within a former backwater zone of a now destroyed dam or weir that can be seen downstream of the study reach. There are no large woody debris or boulders in the reach. The bank vegetation is mostly grass, with a few scattered trees and a bamboo stand at the downstream limit of the study reach. Floodplain vegetation is also mostly grass, with a lawn on the right and a pasture on the left.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	114.50	Q_{bkf} / $Q_{2.0}$:	0.84	
Bankfull Return Interval (R.I.):	1.55	$Q_{Top of Bank}$(cfs):	357.50	R.I.: 7.30
Gage Height (ft):	3.13	$Q_{Active Channel}$ (cfs):	n/a	R.I.: n/a
Q_{bkf} / $Q_{1.5}$:	1.19			

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0160	Flood-prone Width (ft):	458.00
Manning's "n":	0.069	Entrenchment Ratio:	24.23
Mean Bankfull Velocity (ft/sec):	3.66	Width/Depth Ratio:	11.39
u/u^*:	4.11	Channel Sinuosity:	1.29
R/D_{84}:	2.54	Beltwidth:	84
Froude Number:	0.50	Meander Width Ratio:	4.4

BAISMAN RUN AT BROADMOOR, MD
PARTICLE SIZE DISTRIBUTION
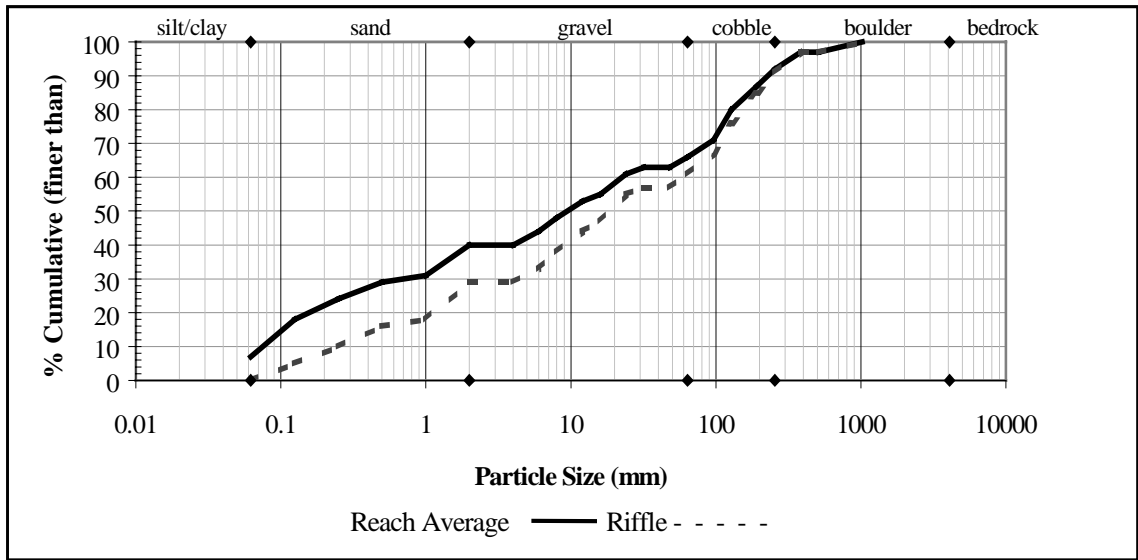
	Particle Size (mm)	
Finer Than	Reach	Riffle
D$_{16}$	0.11	0.49
D$_{35}$	1.34	6.60
D$_{50}$	9.47	18.49
D$_{84}$	160.05	184.87
D$_{95}$	314.60	336.59

STUDY REACH CROSS SECTION
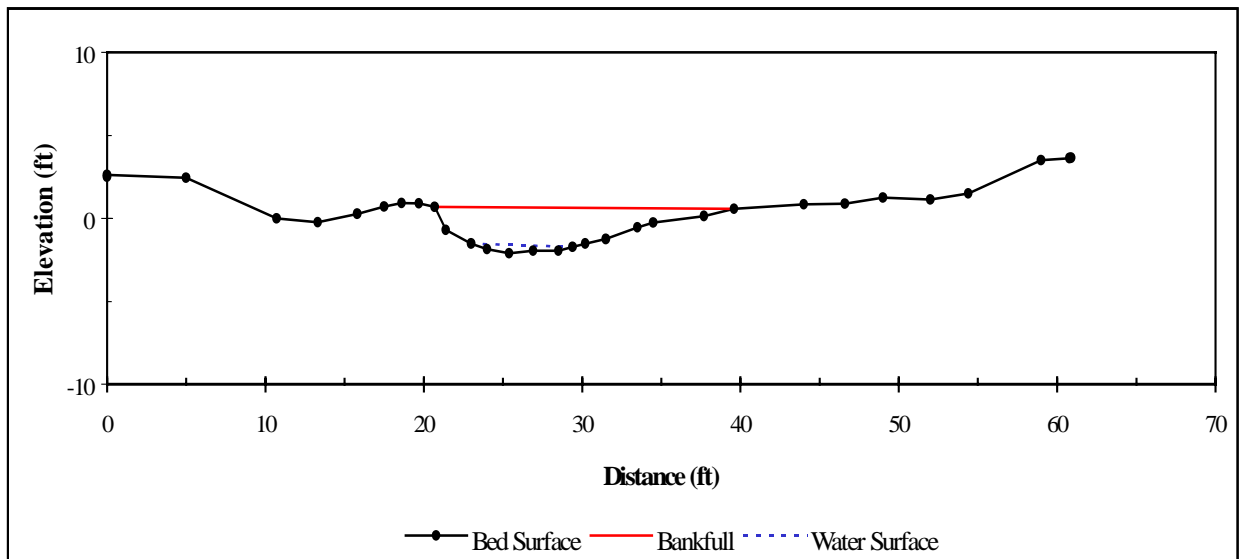
Bankfull Width (ft):	18.90	Mean Bankfull Depth (ft):	1.66
Bankfull Cross-sectional Area (ft^2):	31.32	Maximum Bankfull Depth (ft):	2.77
Hydraulic Radius (ft):	1.54	Wetted Perimeter (ft):	20.34

Baisman Run at Broadmoor, Maryland

Downstream view of classification cross-section

Right bank of classification cross-section

BAISMAN RUN
at Broadmoor, MD
U.S.G.S. Gage 1583580
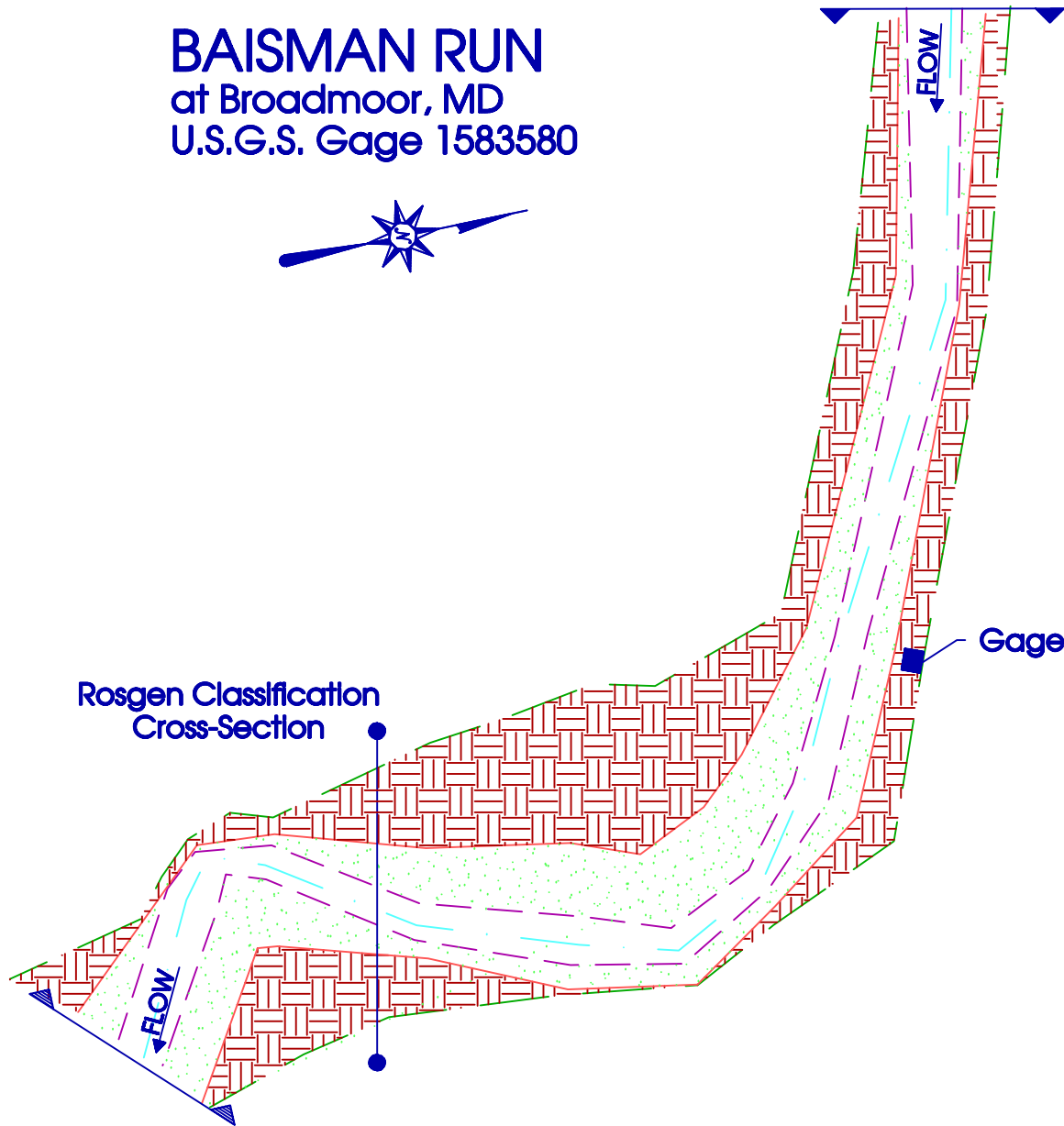
FLOW

Gage

Rosgen Classification Cross-Section

FLOW

LEGEND

Top of Bank :	
Bankfull :	
Edge of Water :	
Thalweg :	
Earth :	
Sand/Gravel :	
Limit of Study Reach:	

Scale (ft):

0   25   50   100

Survey Date: 11/16/98
Study Reach Length: 310'

Classification Cross-Section Monument Locations:
Left Monument Location (+/- 20'):
39* 28' 44.67" N
76* 40' 37.33" W
Elevation: 339'

Right Monument Location (+/-20'):
39* 28' 44.94" N
76* 40' 38.10" W
Elevation: 302'

BASIN RUN AT LIBERTY GROVE, MD
USGS STATION NUMBER: 1579000

Latitude:	39º 39' 30"	Gage Period of Record:	1948 - 1958
Longitude:	76º 06' 10"		1965 - 1976
ADC Map Coordinates:	Cecil / 1989	Mean Annual Discharge (cfs):	6.74
	Map 3 / B12	Rosgen Stream Type:	C4
Drainage Area (sq. mi.):	5.31	Survey Date:	Oct. 1998
Stream Order / Magnitude:	3 / 9		
Percent Imperviousness:	6.79		

Land Use (%):   Residential: 13.78   Agricultural: 63.35   Forest: 18.89   Commercial: 3.97

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 155.60 $Q_{1.5}$: 580.00 $Q_{2.0}$: 808.70
(Log-Pearson Period: 1949 - 1976)

General Study Reach Description: The study reach and the gage reach are the same. The channel exhibits pool/riffle morphology, a regular meander pattern with well-vegetated point bars and some lateral scour, and appears vertically stable. A cut-off channel at one meander has produced a mid-channel island, and another meander has been stabilized with rubble. The overall particle distribution is bi-modal sand and gravel. There are no pieces of large woody debris or boulders in the channel. The reach is in a pasture, and cattle have unrestricted access to the stream. The bank and floodplain vegetation is pasture grass and scattered trees, mostly sycamores.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	613.92	Q_{bkf} / $Q_{2.0}$:	0.76		
Bankfull Return Interval (R.I.):	1.55	$Q_{Top of Bank}$(cfs):	1179.50	R.I.: 3.20	
Gage Height (ft):	3.55	$Q_{Active Channel}$ (cfs):	n/a	R.I.: n/a	
Q_{bkf} / $Q_{1.5}$:	1.06				

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0059	Flood-prone Width (ft):	360.00
Manning's "n":	0.050	Entrenchment Ratio:	7.04
Mean Bankfull Velocity (ft/sec):	6.34	Width/Depth Ratio:	27.04
u/u^*:	5.82	Channel Sinuosity:	1.40
R/D_{84}:	3.77	Beltwidth:	96
Froude Number:	0.81	Meander Width Ratio:	1.9

BASIN RUN AT LIBERTY GROVE, MD
PARTICLE SIZE DISTRIBUTION
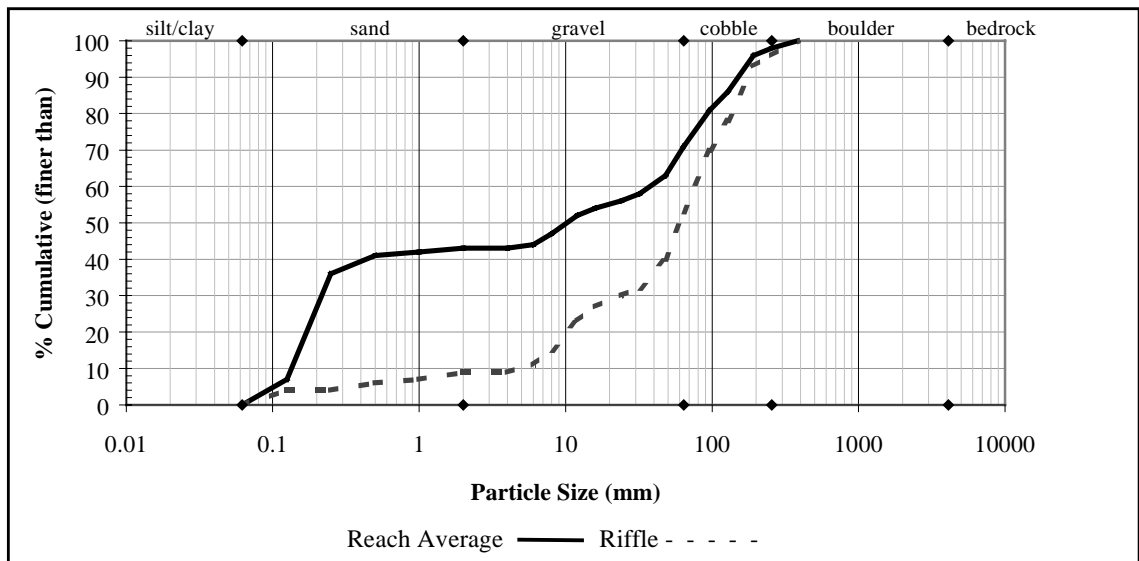
Particle Size (mm)		
Finer Than	Reach	Riffle
D_{16}	0.16	8.42
D_{35}	0.24	37.25
D_{50}	10.31	59.89
D_{84}	112.46	150.54
D_{95}	186.88	232.59

STUDY REACH CROSS SECTION
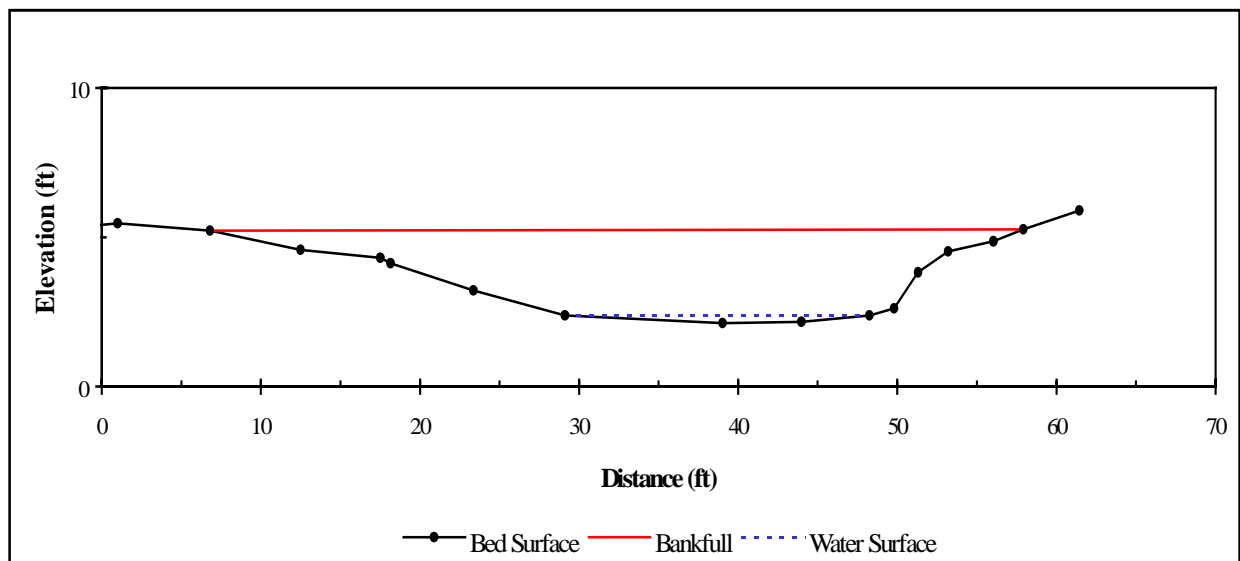
Bankfull Width (ft):	51.11	Mean Bankfull Depth (ft):	1.89
Bankfull Cross-sectional Area (ft^2):	96.83	Maximum Bankfull Depth (ft):	3.11
Hydraulic Radius (ft):	1.86	Wetted Perimeter (ft):	51.96

Basin Run at Liberty Grove, Maryland

Upstream view of classification cross-section

Right bank of classification cross-section

BASIN RUN
at Liberty Grove, MD
U.S.G.S. Gage: 1579000

Gage

Gage Weir

FLOW

Rosgen Classification
Cross-Section

LEGEND

Top of Bank :	– – – – –
Bankfull :	————
Edge of Water :	– – – – –
Thalweg :	— · — · —
Earth :	▦▦▦▦▦
Sand/Gravel :	⣿⣿⣿
Rubble Rip-Rap:	△ △ △ △ △ △△△
Fallen Trees :	
Limit of Study Reach:	▼————▼

Scale (ft):

0   50   100   200

Survey Date: 10/9/98
Study Reach Length: 980'

Classification Cross-Section Monument Locations:
Left Monument Location (+/-):
N/A
N/A
Elev. N/A

Right Monument Location (+/-):
N/A
N/A
Elev. N/A

FLOW
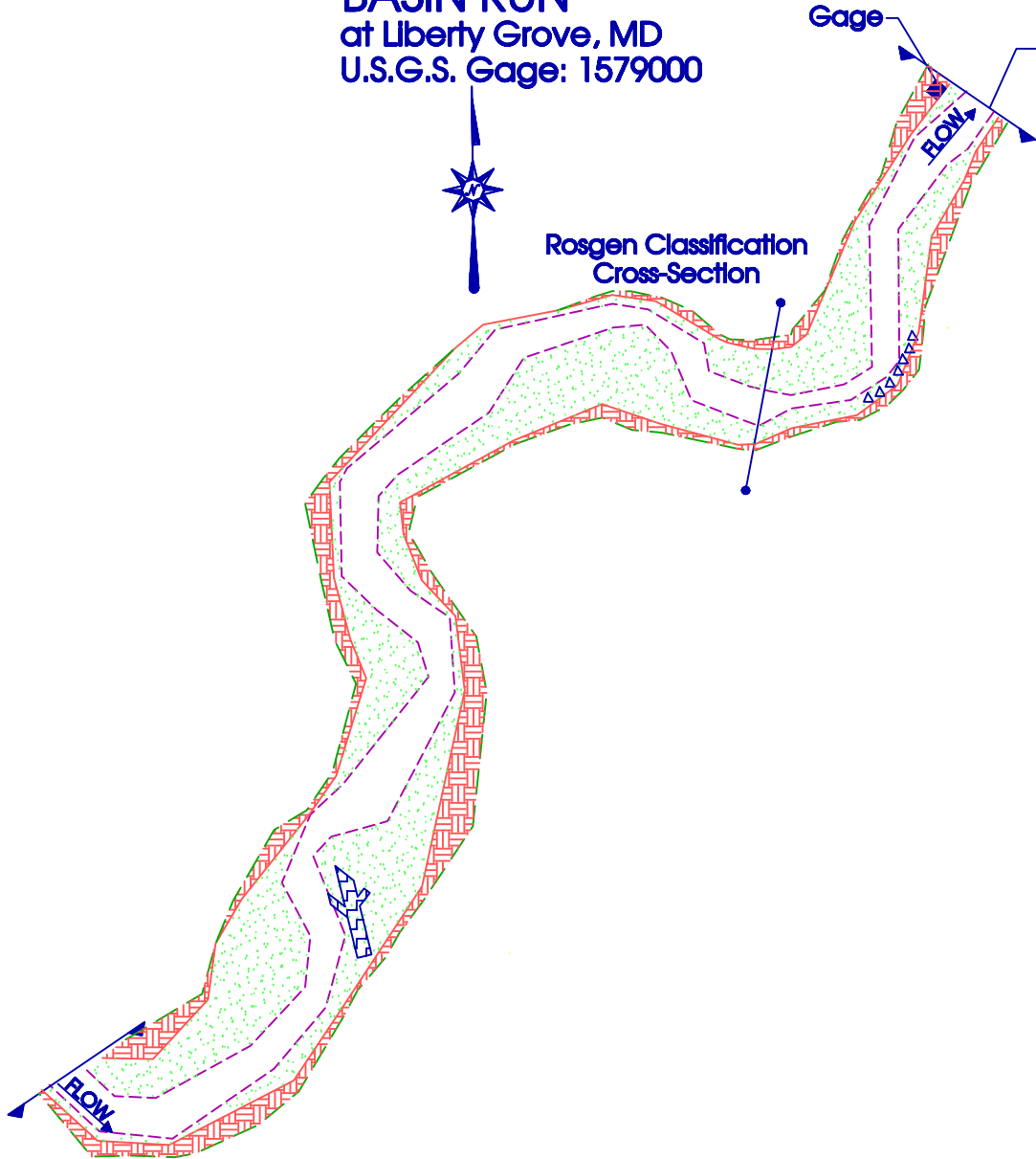
BEAVER RUN NEAR FINKSBURG, MD
USGS STATION NUMBER: 1586210

Latitude:	39° 29' 22"	Gage Period of Record:	1982 - Present
Longitude:	76° 54' 12"	Mean Annual Discharge (cfs):	16.60
ADC Map Coordinates:	Carroll / 1994	Rosgen Stream Type:	C4/1
	Map 26 / A7	Survey Dates	Oct. 1997
Drainage Area (sq. mi.):	14.00		Sept. 1998
Stream Order / Magnitude:	3 / 30		
Percent Imperviousness:	8.59		

Land Use (%):   Residential: 19.03   Agricultural: 51.32   Forest: 25.61   Commercial: 3.69

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 151.80 $Q_{1.5}$: 520.00 $Q_{2.0}$: 733.20
(Log-Pearson Period: 1983 - 1995)

General Study Reach Description: The downstream end of the study reach is 220 feet upstream of the gage. The study reach has pool/riffle features, a regular meander pattern controlled by bedrock with some gabion/rip-rap revetment along the road on a portion of the right bank. The reach exhibits a bi-modal distribution of gravel and bedrock with point- and side-bar depositional features, some lateral scour, and is vertically stable. The reach contains several pieces of large woody debris, one of which spans the channel, and numerous boulders. The bank vegetation is comprised of trees and sparse grass, while the floodplain vegetation is moderately dense forest of hickory, ash, tulip poplar, beech and oak, with a moderately dense understory of spice bush, witch hazel, and rhododendron.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	626.90	Q_{bkf} / $Q_{2.0}$:	0.86	
Bankfull Return Interval (R.I.):	1.73	$Q_{Top of Bank}$(cfs):	n/a	R.I.: n/a
Gage Height (ft):	3.61	$Q_{Active Channel}$ (cfs):	n/a	R.I.: n/a
Q_{bkf} / $Q_{1.5}$:	1.21			

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0050	Flood-prone Width (ft):	126.40
Manning's "n":	0.032	Entrenchment Ratio:	3.13
Mean Bankfull Velocity (ft/sec):	5.93	Width/Depth Ratio:	15.49
u/u*:	9.41	Channel Sinuosity:	1.06
R/D_{84}:	11.04	Beltwidth:	87
Froude Number:	0.65	Meander Width Ratio:	2.2

BEAVER RUN NEAR FINKSBURG, MD
PARTICLE SIZE DISTRIBUTION
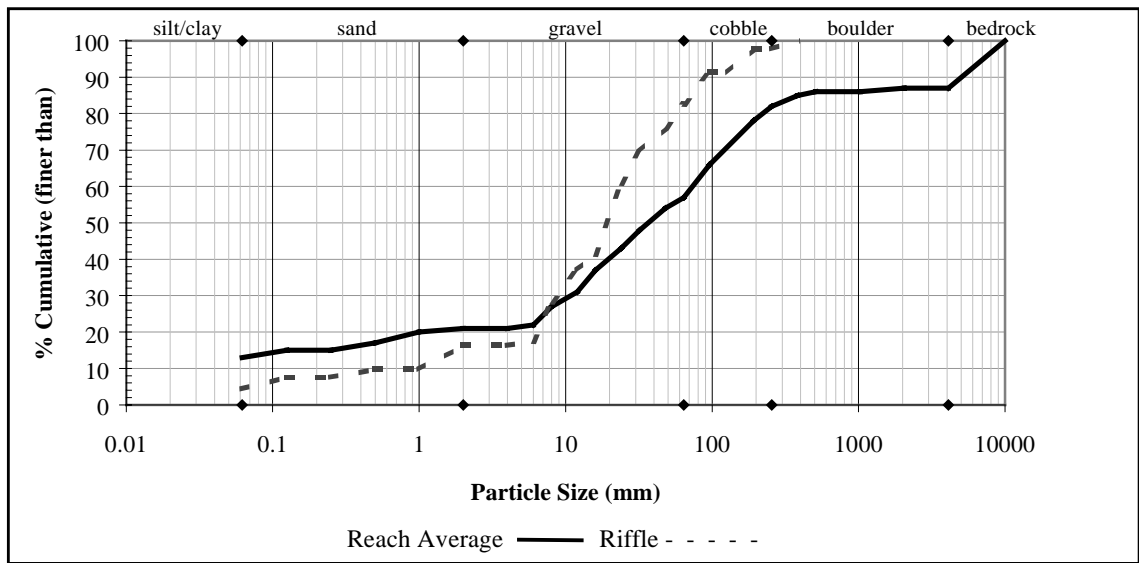
Particle Size (mm)		
Finer Than	Reach	Riffle
D_{16}	0.35	1.94
D_{35}	14.54	10.95
D_{50}	36.63	19.16
D_{84}	335.45	68.29
D_{95}	Bedrock	161.06

STUDY REACH CROSS SECTION
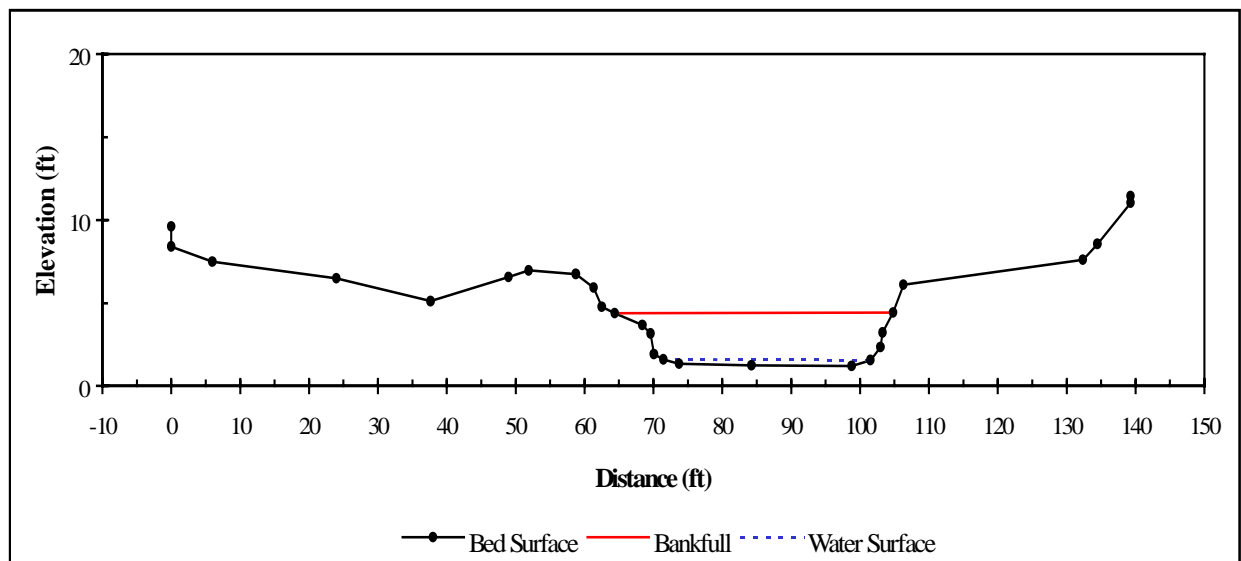
Bankfull Width (ft):	40.43	Bankfull Depth (ft):	2.61
Bankfull Cross-sectional Area (ft^2):	105.69	Maximum Bankfull Depth (ft):	3.20
Hydraulic Radius (ft):	2.47	Wetted Perimeter (ft):	42.74

Beaver Run near Finksburg, Maryland

Upstream view of classification cross-section
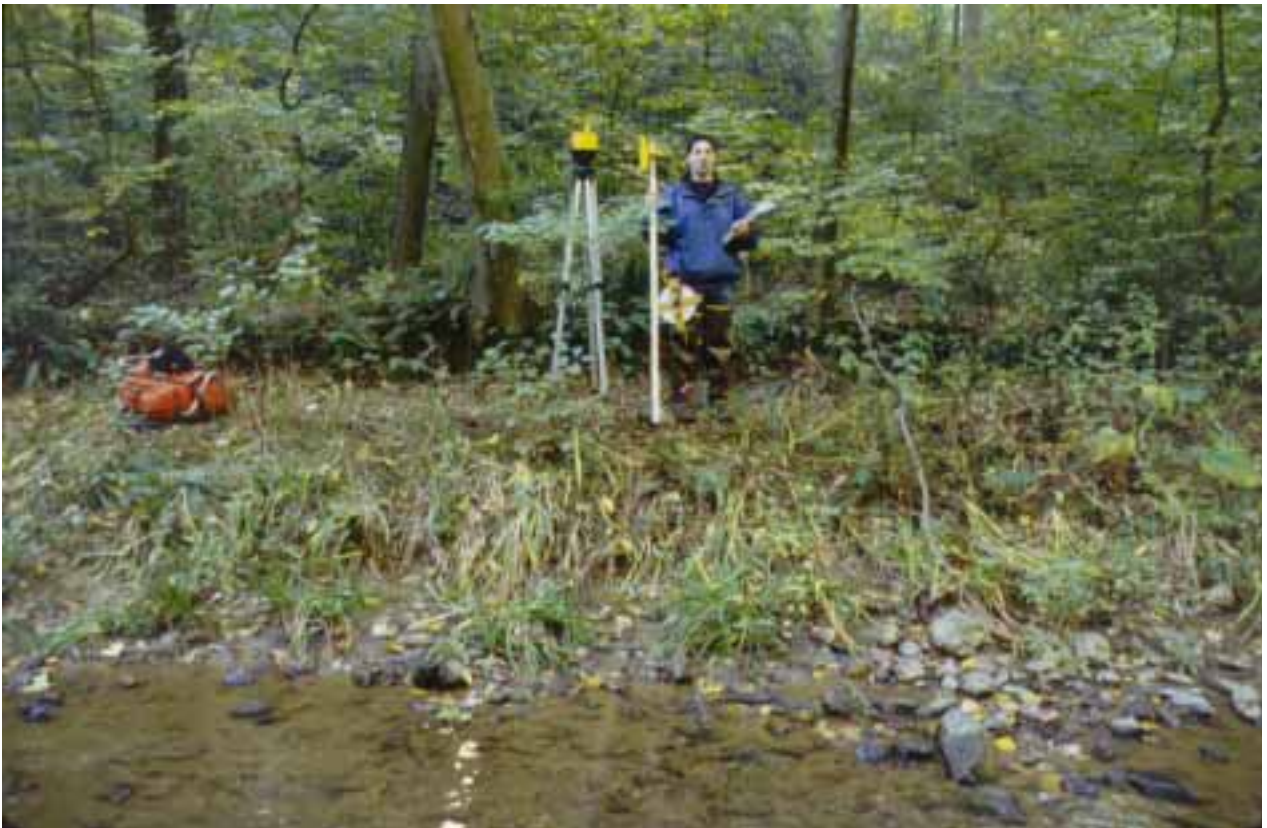
Left bank of classification cross-section

BEAVER RUN
near Finksburg, MD
U.S.G.S. Gage 1586210

FLOW

LEGEND

Top of Bank :	– – – – –
Bankfull :	———
Edge of Water :	– – – – –
Thalweg :	– · – · –
Earth :	(hatched pattern)
Sand/Gravel :	(stippled pattern)
Bed Rock :	(diagonal hatch)
Boulders :	(oval shapes)
Fallen Trees :	(tree symbol)
Rip-Rap:	△ △ △ △ △ △ △ △
Limit of Study Reach:	▼ ▼

Scale (ft): 0 50 100 200

Rosgen Classification Cross-Section

FLOW

Hughsville Road

Gage

Entrance of Tributary

Survey Dates: 9/11/98
Study Reach Length: 1034'
Study Reach 220' U/S of U.S.G.S. Gage

Classification Cross-Section Monument Locations:
Left Monument Location (+/-):   Right Monument Location (+/-):
N/A   N/A
N/A   N/A

BEAVERDAM RUN AT COCKEYSVILLE, MD
USGS STATION NUMBER: 1583600

Latitude: 39° 29' 13" Gage Period of Record: 1982 - Present
Longitude: 76° 38' 42" Mean Annual Discharge (cfs): 30.50
ADC Map Coordinates: Baltimore / 1993 Rosgen Stream Type: C5/1c-
Map 18 / G-H 4 Survey Dates: Oct. 1997
Drainage Area (sq. mi.): 20.90 Nov. 1998
Stream Order / Magnitude: 3 / 16
Percent Imperviousness: 19.28

Land Use (%): Residential: 28.67 Agricultural: 24.61 Forest: 30.91 Commercial: 11.30

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 341.80 $Q_{1.5}$: 800.00 $Q_{2.0}$: 997.60
(Log-Pearson Period: 1983 - 1995)

General Study Reach Description: The upstream end of the study reach is 600 feet downstream of the gage. The reach has pool/riffle features, a meander pattern that may have been straightened in the past and is partially controlled by bedrock, point- and side-bar depositional features, some lateral scour, and appears vertically stable. There are several pieces of large woody debris, two of which extend at least to mid-channel, and several boulders. The bank and floodplain vegetation consists of moderately dense young forest of ash, red maple, and sycamore, with a low-density understory of saplings and shrubs.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs): 662.50 Q_{bkf} / $Q_{2.0}$: 0.66
Bankfull Return Interval (R.I.): 1.26 $Q_{Top of Bank}$(cfs): 980.30 R.I.: 2.00
Gage Height (ft): 5.15 $Q_{Active Channel}$ (cfs): n/a R.I.: n/a
Q_{bkf} / $Q_{1.5}$: 0.83

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft): 0.0008 Flood-prone Width (ft): 463.50
Manning's "n": 0.023 Entrenchment Ratio: 10.73
Mean Bankfull Velocity (ft/sec): 4.09 Width/Depth Ratio: 11.52
u/u*: 14.10 Channel Sinuosity: 1.13
R/D$_{84}$: 80.01 Beltwidth: 95
Froude Number: 0.37 Meander Width Ratio: 2.2

BEAVERDAM RUN AT COCKEYSVILLE, MD
PARTICLE SIZE DISTRIBUTION
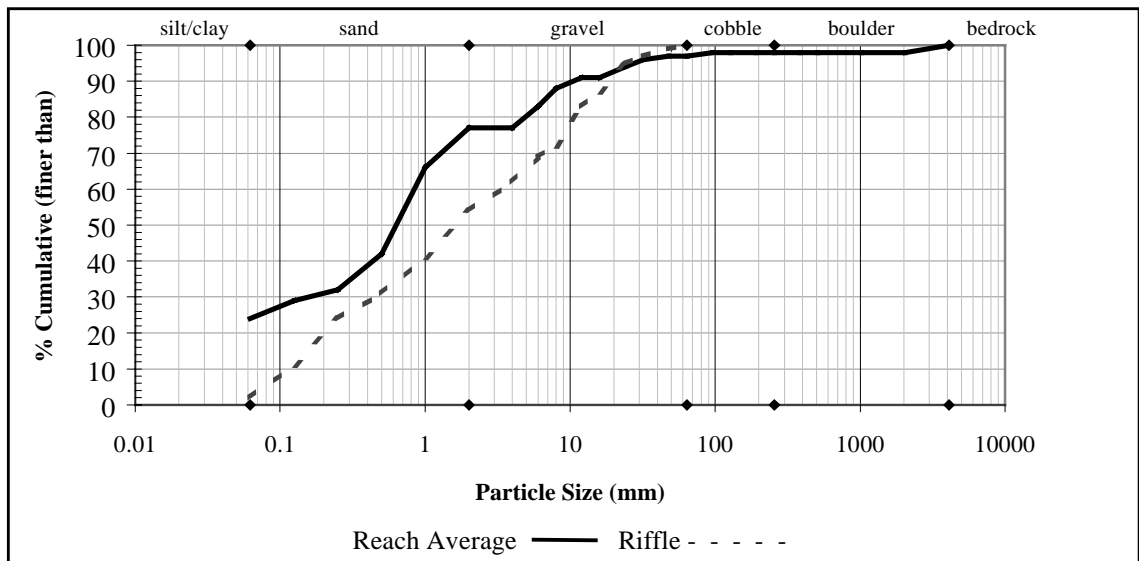
Particle Size (mm)		
Finer Than	Reach	Riffle
D_{16}	n/a	0.16
D_{35}	0.31	0.66
D_{50}	0.63	1.62
D_{84}	6.36	12.89
D_{95}	27.71	24.00

STUDY REACH CROSS SECTION
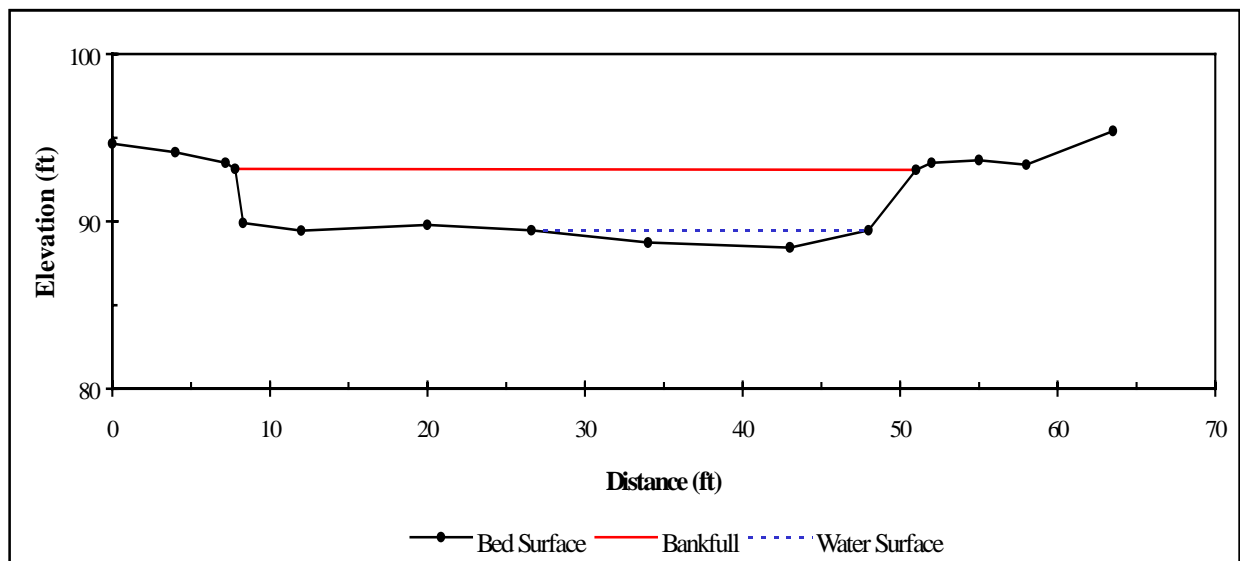
Bankfull Width (ft):	43.20	Bankfull Depth (ft):	3.75
Bankfull Cross-sectional Area (ft^2):	161.98	Maximum Bankfull Depth (ft):	4.69
Hydraulic Radius (ft):	3.38	Wetted Perimeter (ft):	47.87

Beaverdam Run at Cockeysville, Maryland

Downstream view of classification cross-section

Right bank of classification cross-section

BEAVERDAM RUN
at Cockeysville, MD
U.S.G.S. Gage:1583600

FLOW

Rosgen Classification
Cross-Section

Old Bridge Wall

FLOW

Old Bridge Wall

Entrance of Tributary
from Adjacent Wetland

LEGEND

Top of Bank :	
Bankfull :	
Edge of Water :	
Thalweg :	
Earth :	
Sand/Gravel :	
Bed Rock :	
Boulders :	
Fallen Trees :	
Limit of Study Reach :	
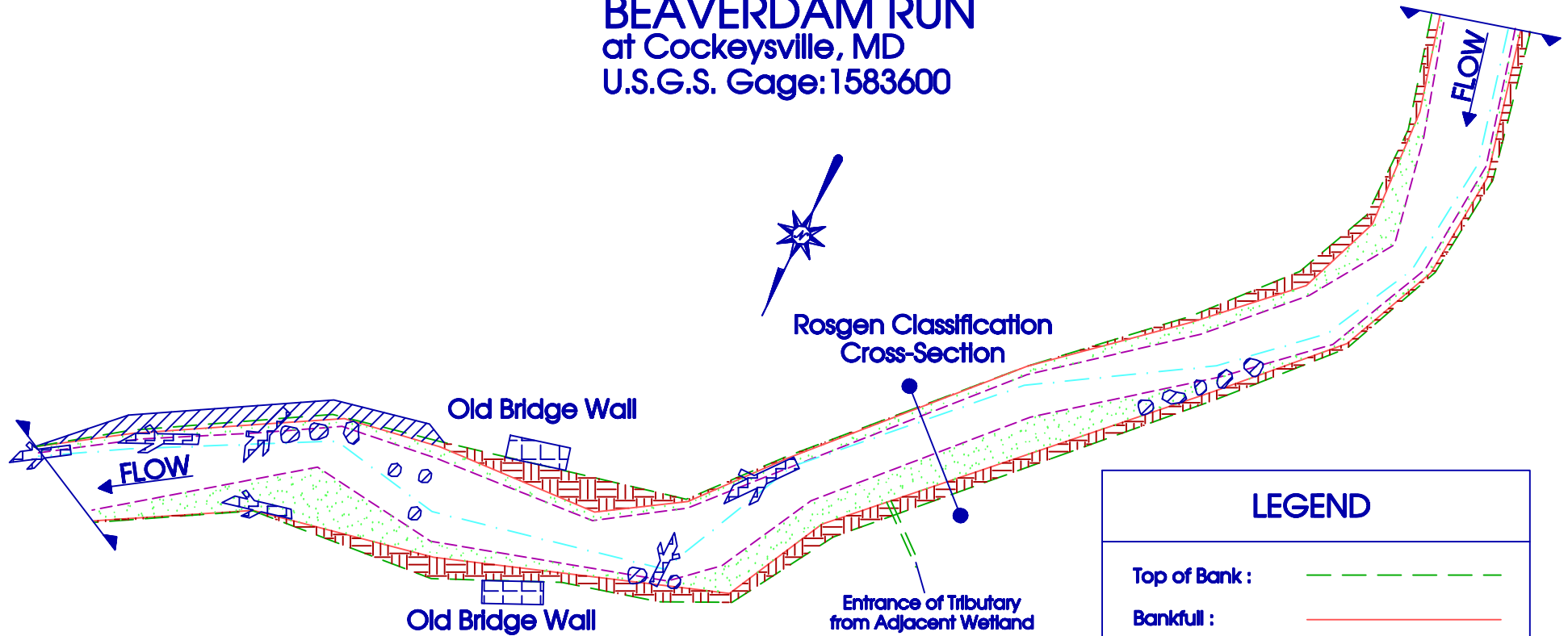
Scale (ft):

0   50   100   200

Survey Date: 11/17/98
Study Reach Length: 926'
Study Reach 600' D/S of U.S.G.S. Gage

BENNETT CREEK AT PARK MILLS, MD
USGS STATION NUMBER: 1643500

Latitude:	39° 17' 40"	Gage Period of Record:	1948 – 1958
Longitude:	77° 24' 30"		1966 - Present
ADC Map Coordinates:	Frederick / 1992	Mean Annual Discharge (cfs):	70.70
	Map 45 / F - G2	Rosgen Stream Type:	C4/1
Drainage Area (sq. mi.):	62.80	Survey Dates:	Nov. 1997
Stream Order / Magnitude:	5 / 122		Feb. 1999
Percent Imperviousness:	3.48		

Land Use (%):   Residential: 9.54   Agricultural: 51.69   Forest: 37.51   Commercial: 1.10

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 783.40 $Q_{1.5}$: 1800.00 $Q_{2.0}$: 2312.30
(Log-Pearson Period: 1949 – 1995)

General Study Reach Description: The downstream end of the study reach is 1,624 feet upstream of the gage, because the intervening section is a highly uniform run that may have been channelized in the past. The study reach channel has pool/riffle features, a fairly straight, bedrock-controlled, meander pattern with point- and side-bar depositional features, some lateral scour, and appears vertically stable. There are a few pieces of large woody debris along the banks of one riffle, and several large boulders are scattered throughout the reach. The bank and floodplain vegetation is moderately dense forest, consisting of beech, hemlock, oak and sycamore, with a low-density understory of saplings, spice bush, and mountain laurel.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	1867.00	Q_{bkf} / $Q_{2.0}$:	0.81		
Bankfull Return Interval (R.I.):	1.55	$Q_{Top of Bank}$(cfs):	n/a	R.I.: n/a	
Gage Height (ft):	6.28	$Q_{Active Channel}$ (cfs):	214.80	R.I.: <1.005	
Q_{bkf} / $Q_{1.5}$:	1.04				

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0019	Flood-prone Width (ft):	271.00
Manning's "n":	0.038	Entrenchment Ratio:	3.26
Mean Bankfull Velocity (ft/sec):	4.69	Width/Depth Ratio:	17.41
u/u*:	8.85	Channel Sinuosity:	1.11
R/D_{84}:	16.36	Beltwidth:	161
Froude Number:	0.38	Meander Width Ratio:	1.9

BENNETT CREEK AT PARK MILLS, MD
PARTICLE SIZE DISTRIBUTION
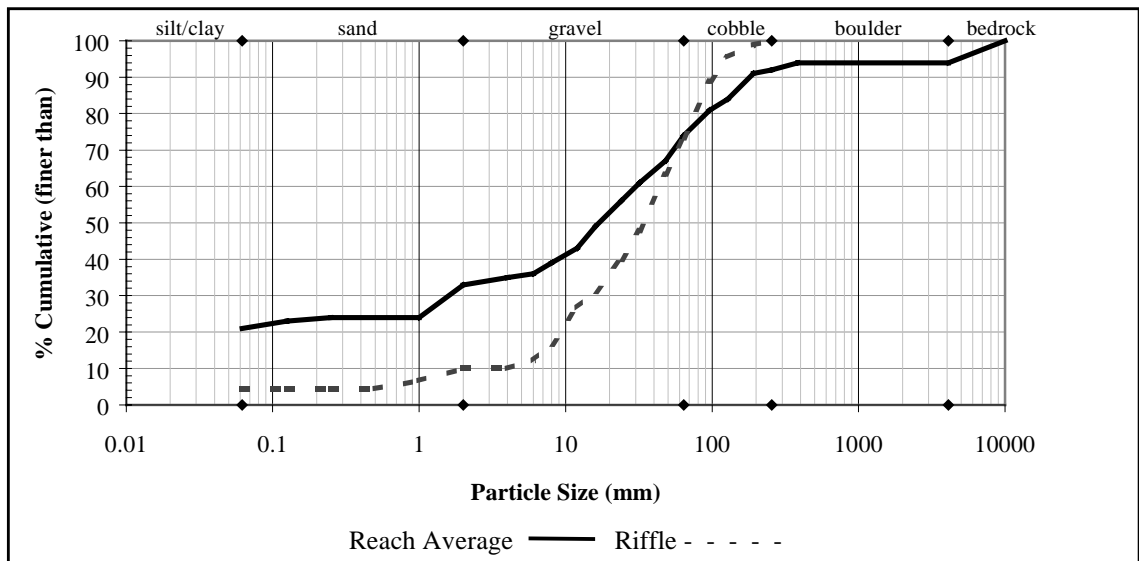
Particle Size (mm)		
Finer Than	Reach	Riffle
D$_{16}$	n/a	7.66
D$_{35}$	4.00	19.11
D$_{50}$	16.95	33.91
D$_{84}$	128.00	84.51
D$_{95}$	Bedrock	124.97

STUDY REACH CROSS SECTION
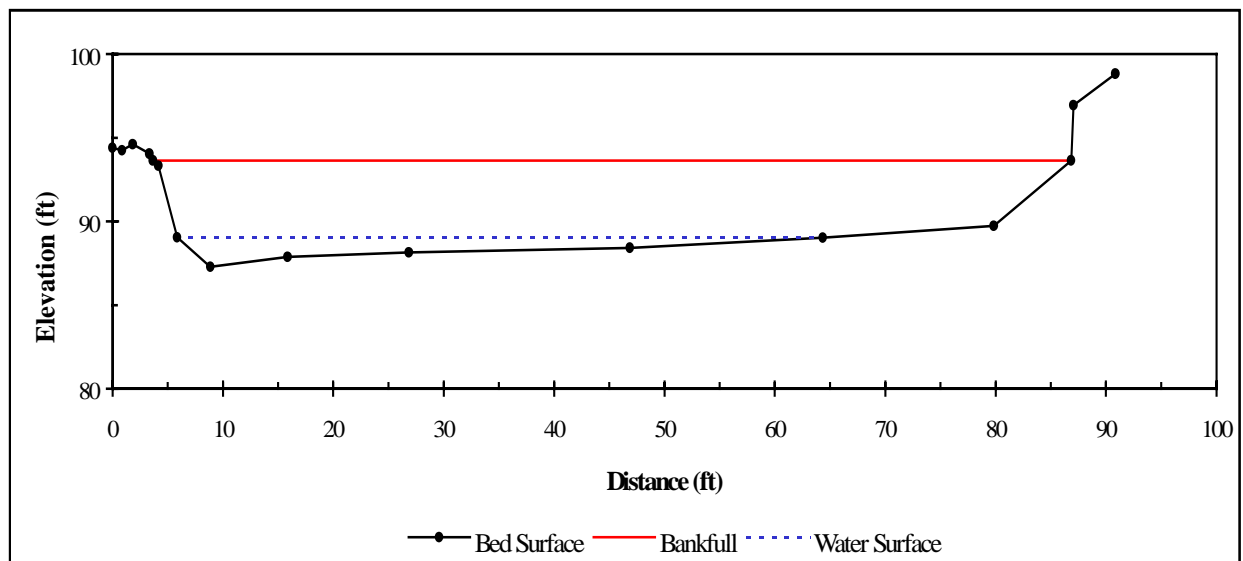
Bankfull Width (ft):	83.20	Mean Bankfull Depth (ft):	4.78
Bankfull Cross-sectional Area (ft^2):	398.03	Maximum Bankfull Depth (ft):	6.37
Hydraulic Radius (ft):	4.54	Wetted Perimeter (ft):	87.76

Bennett Creek at Park Mills, Maryland

Downstream view of classification cross-section

Left bank of classification cross-section

BENNETT CREEK
at Park Mills, MD
U.S.G.S Gage:1643500

FLOW

FLOW

Rosgen Classification
Cross-Section

LEGEND

Top of Bank :	– – – – –
Bankfull :	———————
Edge of Water :	– – – – –
Thalweg :	–·–·–·–
Earth :	▦▦▦▦
Sand/Gravel :	⸰⸰⸰⸰⸰
Bedrock :	⫽⫽⫽⫽⫽
Boulders :	⬭⬭
Fallen Trees :	⤐
Limit of Study Reach:	◄——————►
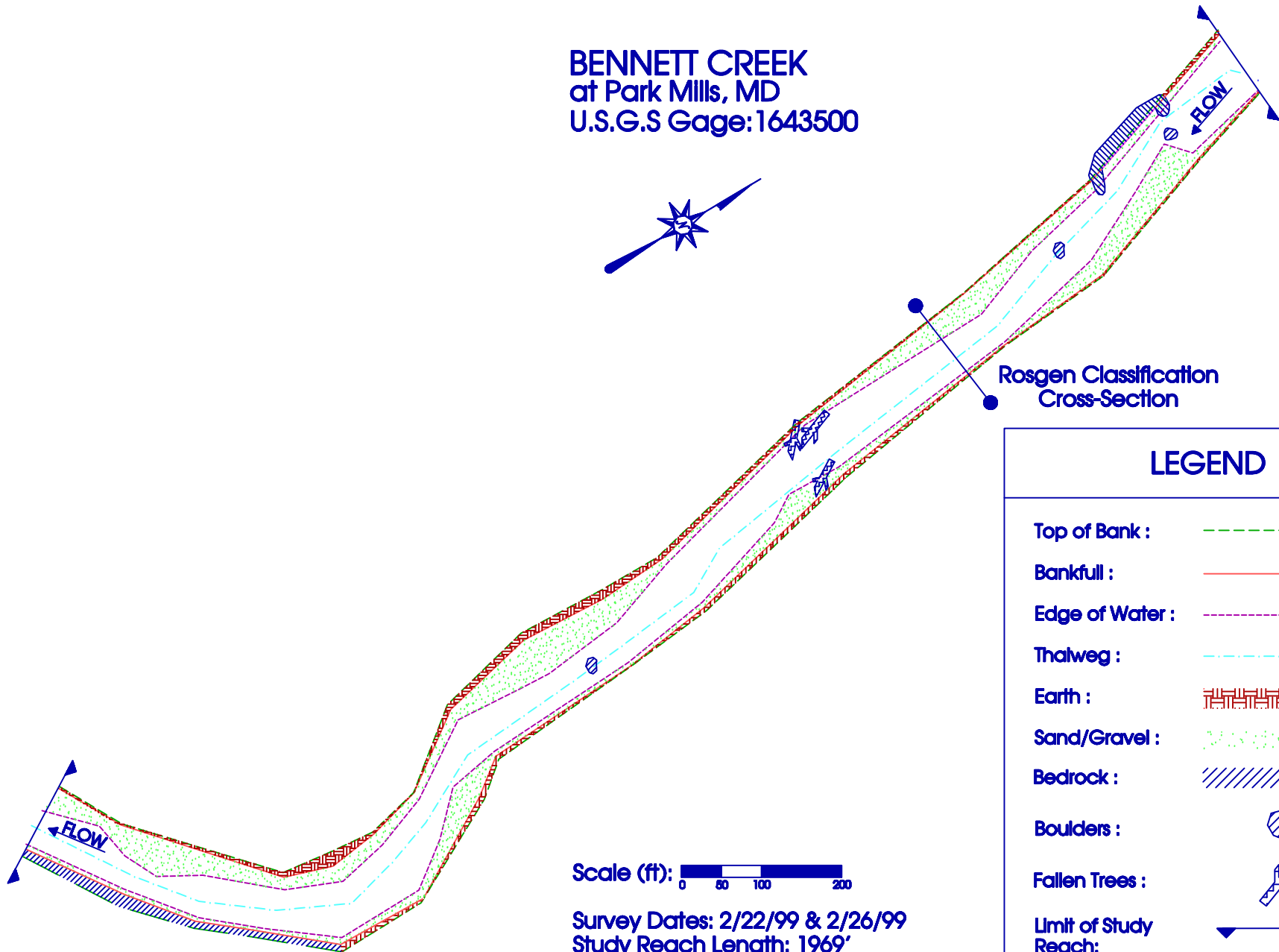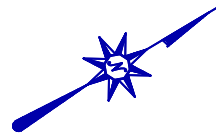
Scale (ft):
0   50   100   200

Survey Dates: 2/22/99 & 2/26/99
Study Reach Length: 1969'
Study Reach 1624' U/S of U.S.G.S. Gage

BIG ELK CREEK AT ELK MILLS, MD
USGS STATION NUMBER: 1495000

Latitude:	39° 39' 26"	Gage Period of Record:	1932 - Present
Longitude:	75° 49' 20"	Mean Annual Discharge (cfs):	69.40
ADC Map Coordinates:	Cecil / 1989	Rosgen Stream Type:	C4/1
	Map 7 / C - D12	Survey Dates:	Sept. 1997
Drainage Area (sq. mi.):	52.60		Aug. 2000
Stream Order / Magnitude:	4 / 67		
Percent Imperviousness:	4.05		

Land Use (%): Residential: 2.68   Agricultural: 76.69   Forest: 16.27   Commercial: 3.79

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 723.50 $Q_{1.5}$: 2200.00 $Q_{2.0}$: 2883.00
(Log-Pearson Period: 1984 – 2000)

General Study Reach Description: The upstream end of the study reach is 481 feet downstream of the gage, because the intervening reach is an atypically long and steep riffle. The study reach has pool/riffle features, a straight meander pattern with sidebars and low lateral scour. An active quarry operation on the left floodplain may have altered the channel alignment. Large woody debris is negligible, but large boulders are distributed through the reach. The vegetation on both banks is moderately dense forest, consisting of sycamore, red maple, alder and willow, with a dense understory of blackberry and multiflora rose. The quarry encroaches on the left floodplain, while the right floodplain is old field.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	2099.00	Q_{bkf} / $Q_{2.0}$:	0.73	
Bankfull Return Interval (R.I.):	1.45	$Q_{Top of Bank}$(cfs):	5178.00	R.I.: 5.50
Gage Height (ft):	6.10	$Q_{Active Channel}$ (cfs):	742.30	R.I.: 1.01
Q_{bkf} / $Q_{1.5}$:	0.95			

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0014	Flood-prone Width (ft):	407.00
Manning's "n":	0.058	Entrenchment Ratio:	5.25
Mean Bankfull Velocity (ft/sec):	6.14	Width/Depth Ratio:	17.57
u/u*:	5.68	Channel Sinuosity:	1.04
R/D_{84}:	5.50	Beltwidth:	210
Froude Number:	0.52	Meander Width Ratio:	2.7

BIG ELK CREEK AT ELK MILLS, MD
PARTICLE SIZE DISTRIBUTION
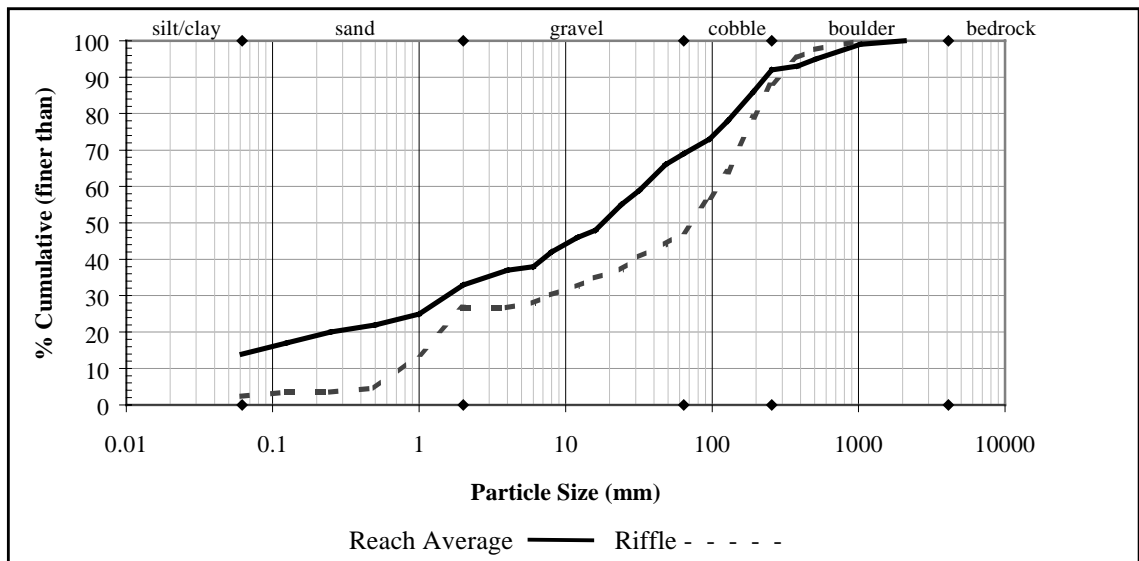
Particle Size (mm)		
Finer Than	Reach	Riffle
D$_{16}$	0.10	1.12
D$_{35}$	2.83	16.33
D$_{50}$	17.97	70.83
D$_{84}$	173.49	223.62
D$_{95}$	512.00	376.29

STUDY REACH CROSS SECTION
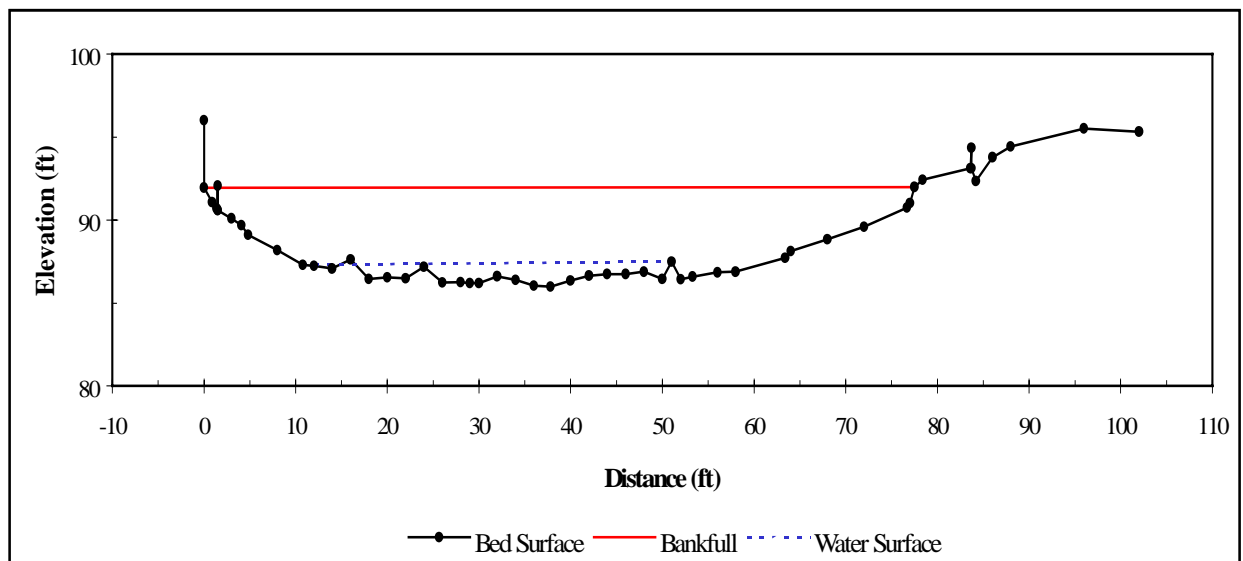
Bankfull Width (ft):	77.50	Mean Bankfull Depth (ft):	4.41
Bankfull Cross-sectional Area (ft^2):	341.70	Maximum Bankfull Depth (ft):	5.97
Hydraulic Radius (ft):	4.04	Wetted Perimeter (ft):	84.63

Big Elk Creek at Elk Mills, Maryland

Upstream view of classification cross-section

Right bank of classification cross-section

BIG ELK CREEK
at Elk Mills, MD
U.S.G.S. Gage 1495000

S

Rosgen Classification
Cross-Section

FLOW

Pump for Quarry

FLOW

Gage House

ROUTE 277

Scale (ft):

0 50 100 200

Survey Dates: 1/13/99 & 1/14/99
Study Reach Length: 1808'
Study Reach 487' D/S of U.S.G.S. Gage

Classification Cross-Section Monument Locations:
Left Monument Location (+/-):
N/A
N/A
Elev. N/A

Right Monument Location (+/-16'):
39°39'08.06" N
75°49'23.96" W
Elev. 75'

LEGEND

Top of Bank :	– – – – –
Bankfull :	————
Edge of Water :	– – – – –
Thalweg :	– – – – –
Earth :	
Sand/Gravel :	
Boulders :	
Fallen Trees :	
Limit of Study Reach:	

BIG PIPE CREEK AT BRUCEVILLE, MD
USGS STATION NUMBER: 1639500

Latitude:	39° 36' 45"	Gage Period of Record:	1947 - Present
Longitude:	77° 14' 10"	Mean Annual Discharge (cfs):	115.00
ADC Map Coordinates:	Carroll / 1994	Rosgen Stream Type:	C4/1
	Map 9 / A 10-11	Survey Dates:	Nov. 1997
Drainage Area (sq. mi.):	102.00		Feb. 1999
Stream Order / Magnitude:	4 / 170		
Percent Imperviousness:	3.54		

Land Use (%):   Residential: 9.49   Agricultural: 66.52   Forest: 22.29   Commercial: 1.31

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 1327.60 $Q_{1.5}$: 2600.00 $Q_{2.0}$: 3266.00
(Log-Pearson Period: 1948 - 1995)

General Study Reach Description: The upstream end of the study reach is 244 feet downstream of the gage. The channel has pool/riffle features, a bedrock-controlled meander pattern, point- and side-bar depositional features, some lateral scour, and is stabilized vertically by bedrock outcrops. There are several pieces of large woody debris distributed through the reach, one spans the full channel width. Numerous boulders occur in the lower third of the reach. The bank vegetation is moderately dense trees consisting of sycamore, red maple and oak, while the floodplain vegetation is a mix of pasture, cropland, and moderately dense forest with a low-density understory of shrubs and saplings.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	2658.00	Q_{bkf} / $Q_{2.0}$:	0.81	
Bankfull Return Interval (R.I.):	1.55	$Q_{Top of Bank}$(cfs):	n/a	R.I.: n/a
Gage Height (ft):	7.20	$Q_{Active Channel}$ (cfs):	1945.00	R.I.: 1.15
Q_{bkf} / $Q_{1.5}$:	1.02			

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0013	Flood-prone Width (ft):	318.00
Manning's "n":	0.033	Entrenchment Ratio:	3.69
Mean Bankfull Velocity (ft/sec):	5.12	Width/Depth Ratio:	14.32
u/u*:	10.67	Channel Sinuosity:	1.45
R/D_{84}:	7.96	Beltwidth:	625
Froude Number:	0.37	Meander Width Ratio:	7.3

BIG PIPE CREEK AT BRUCEVILLE, MD
PARTICLE SIZE DISTRIBUTION
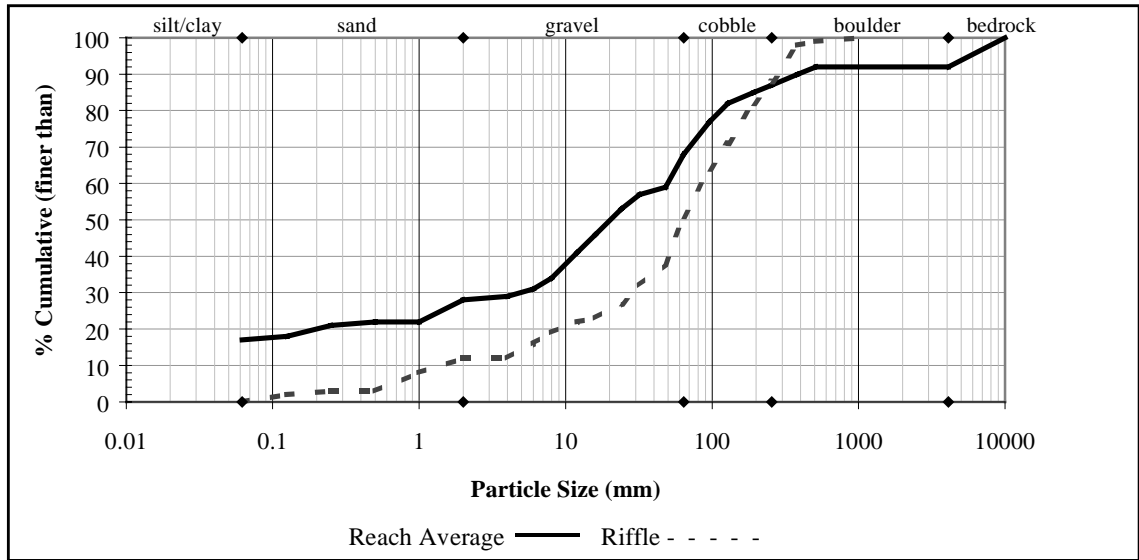
Particle Size (mm)		
Finer Than	Reach	Riffle
D_{16}	n/a	6.23
D_{35}	8.48	39.19
D_{50}	20.17	62.48
D_{84}	167.73	210.51
D_{95}	Bedrock	343.10

STUDY REACH CROSS SECTION
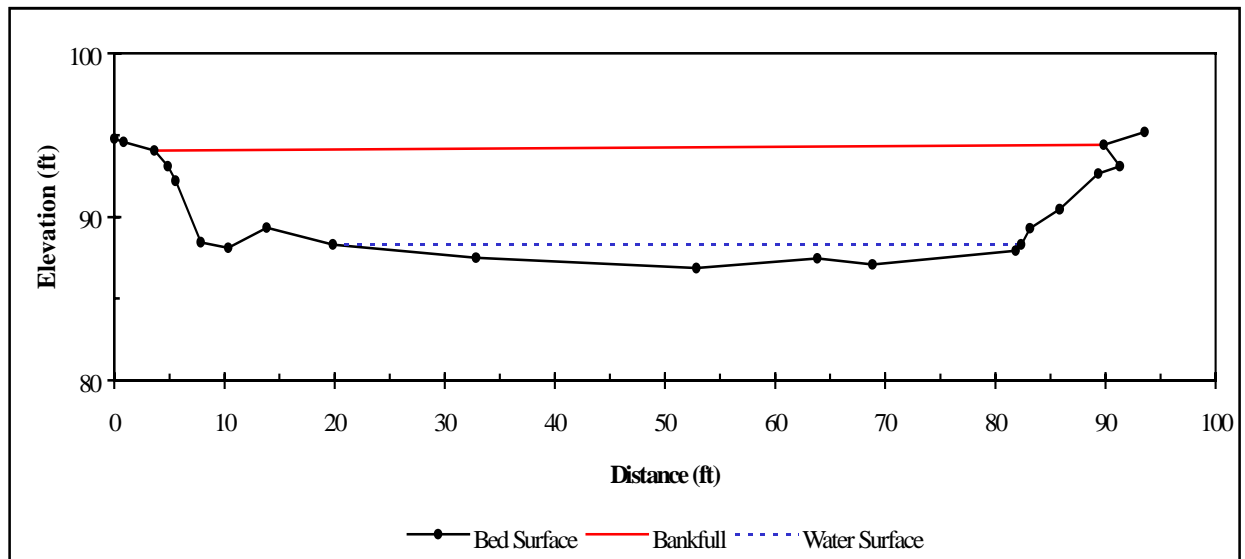
Bankfull Width (ft):	86.20	Mean Bankfull Depth (ft):	6.02
Bankfull Cross-sectional Area (ft²):	518.65	Maximum Bankfull Depth (ft):	7.27
Hydraulic Radius (ft):	5.49	Wetted Perimeter (ft):	94.39

Big Pipe Creek at Bruceville, Maryland

Upstream view of classification cross-section

Right bank of classification cross-section

BIG PIPE CREEK
at Bruceville, MD
U.S.G.S. Gage Number:1639500

N

FLOW

Rosgen Classification
Cross-Section

Bruceville Road

Road
Culvert

FLOW

LEGEND

Top of Bank :	
Bankfull :	
Edge of Water :	
Thalweg :	
Earth :	
Sand/Gravel :	
Bed Rock :	
Boulders :	
Fallen Trees :	
Limit of Study Reach:	

Scale (ft):

0   50   100   200

Survey Dates: 2/5/99 & 2/8/99
Study Reach Length: 2189'
Study Reach: 244' D/S of U.S.G.S. Gage
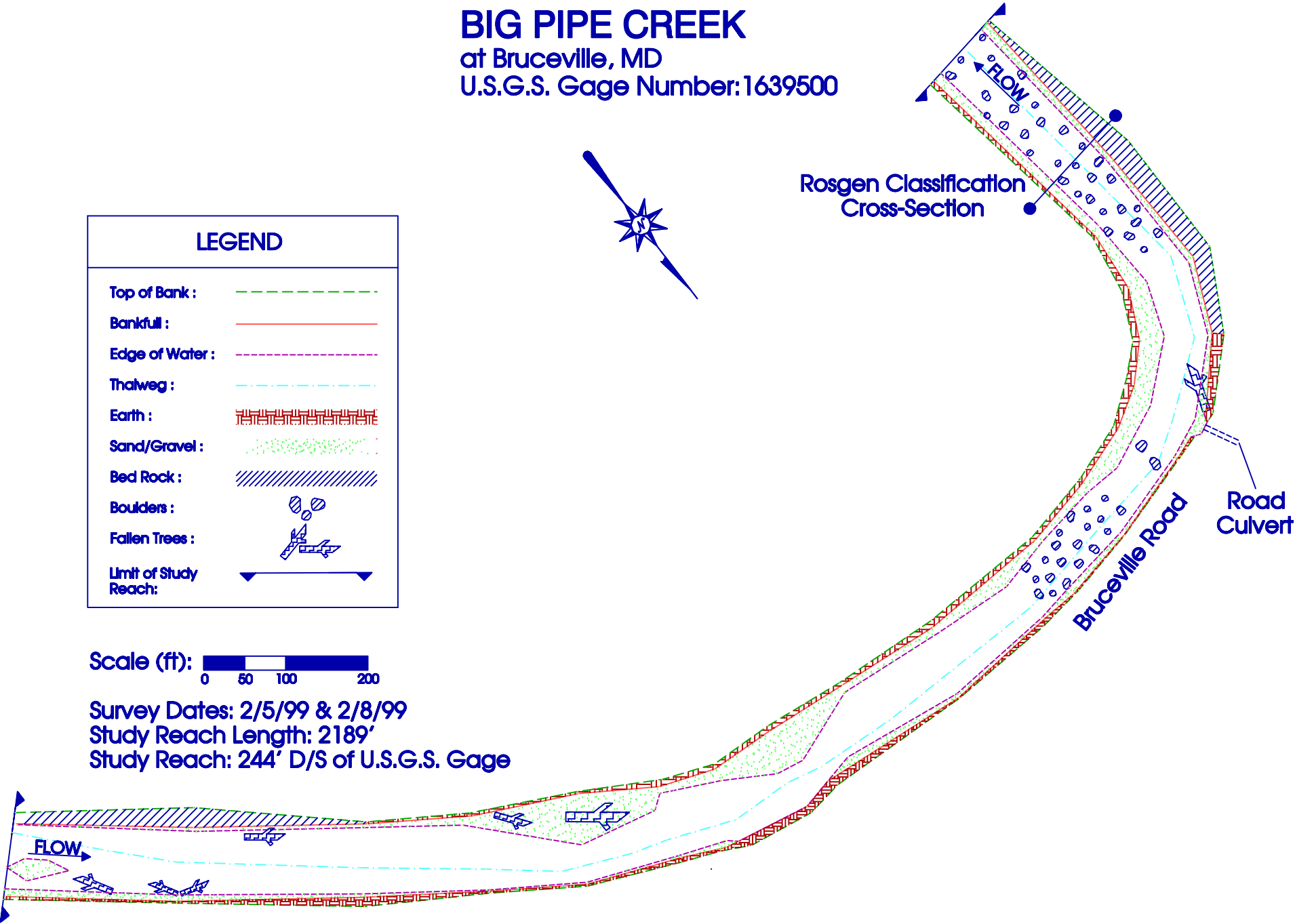
CRANBERRY BRANCH NEAR WESTMINSTER, MD
USGS STATION NUMBER: 1585500

Latitude:	39° 35' 35"	Gage Period of Record:	1949 - Present
Longitude:	76° 58' 05"	Mean Annual Discharge (cfs):	3.31
ADC Map Coordinates:	Carroll / 1994	Rosgen Stream Type:	C4
	Map 20 / A1	Survey Dates:	Oct. 1997
Drainage Area (sq. mi.):	3.40		Sept. 1998
Stream Order / Magnitude:	2 / 6		
Percent Imperviousness:	5.27		

Land Use (%):   Residential: 13.53   Agricultural: 62.53   Forest: 20.40   Commercial: 2.22

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 30.20 $Q_{1.5}$: 150.00 $Q_{2.0}$: 234.30
(Log-Pearson Period: 1949 - 1995)

General Study Reach Description: The downstream end of the study reach is 137 feet upstream of the gage, because of ponding at the gage. The reach has pool/riffle features, a regular meander pattern, point-bar depositional features, some lateral scour, and appears vertically stable. There are numerous pieces of large woody debris throughout the reach, with several spanning the entire width. The reach is located in a pasture, and livestock have unrestricted access to the stream. The bank and floodplain vegetation is pasture with scattered trees, mostly willow and box elder. Upstream and downstream of the study reach the channel appears straightened.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	162.40	Q_{bkf} / $Q_{2.0}$:	0.69		
Bankfull Return Interval (R.I.):	1.57	$Q_{Top of Bank}$(cfs):	589.20	R.I.:	5.40
Gage Height (ft):	3.20	$Q_{Active Channel}$ (cfs):	37.06	R.I.:	1.02
Q_{bkf} / $Q_{1.5}$:	1.08				

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0061	Flood-prone Width (ft):	340.00
Manning's "n":	0.029	Entrenchment Ratio:	17.79
Mean Bankfull Velocity (ft/sec):	5.22	Width/Depth Ratio:	11.72
u/u*:	9.67	Channel Sinuosity:	1.60
R/D_{84}:	21.77	Beltwidth:	80
Froude Number:	0.72	Meander Width Ratio:	4.2

CRANBERRY BRANCH NEAR WESTMINSTER, MD
PARTICLE SIZE DISTRIBUTION
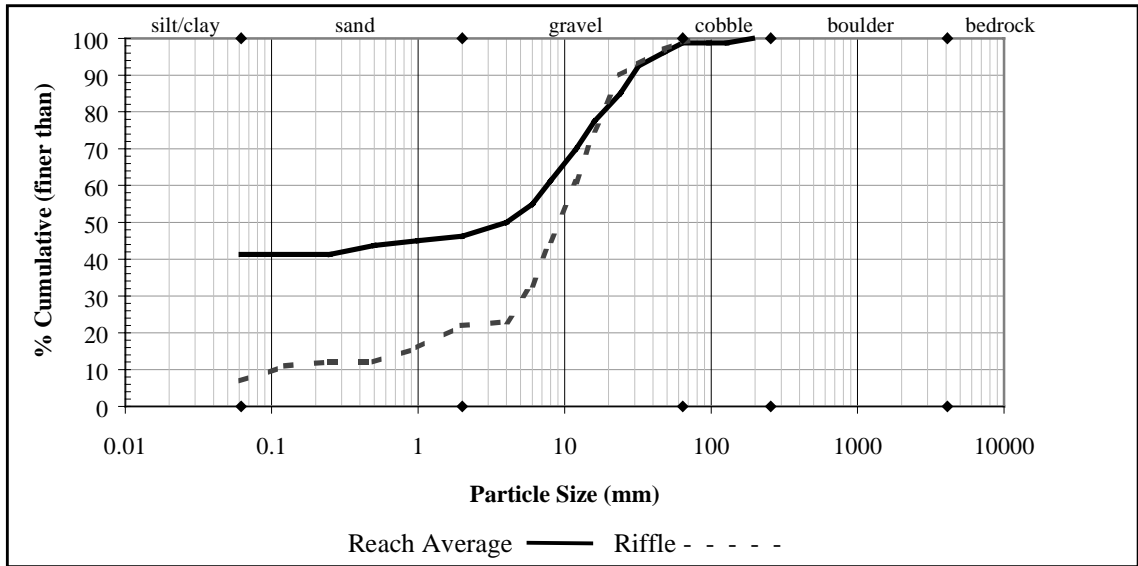
Particle Size (mm)		
Finer Than	Reach	Riffle
D_{16}	n/a	1.00
D_{35}	n/a	6.29
D_{50}	4.00	9.08
D_{84}	22.74	20.41
D_{95}	41.93	39.19

STUDY REACH CROSS SECTION
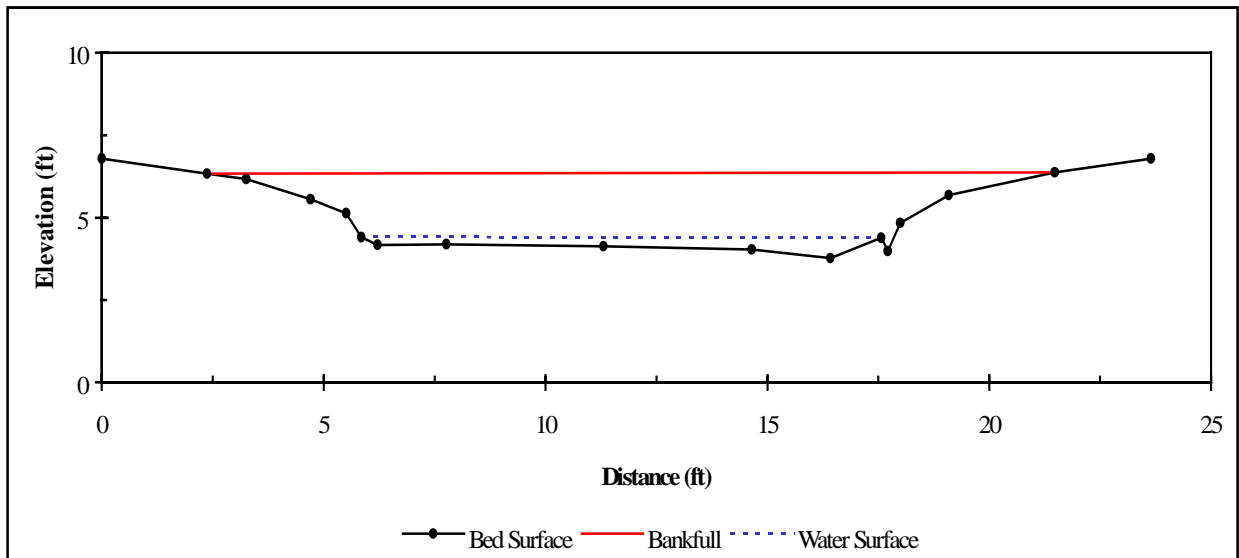
Bankfull Width (ft):	19.11	Mean Bankfull Depth (ft):	1.63
Bankfull Cross-sectional Area (ft^2):	31.13	Maximum Bankfull Depth (ft):	2.56
Hydraulic Radius (ft):	1.46	Wetted Perimeter (ft):	21.35

Cranberry Branch near Westminster, Maryland

Upstream view of classification cross-section

Left bank of classification cross-section

CRANBERRY BRANCH
near Westminster, MD
U.S.G.S. Gage: 1585500

Rosgen Classification
Cross-Section

FLOW

Groundwater
Well

FLOW

Gage

Weir

Private Driveway

LEGEND

Top of Bank :	
Bankfull :	
Edge of Water :	
Thalweg :	
Earth :	
Sand/Gravel :	
Bed Rock :	
Fallen Trees :	
Limit of Study Reach:	

Scale (ft):

| 0 | 25 | 50 | 100 |

Survey Date: 9/9/98
Study Reach Length: 443'
Study Reach: 135' U/S
 of U.S.G.S. Gage

Classification Cross-Section
Mounument Locations:
Left Monument Location (+/- 25'):
39° 35' 36.38" N
76° 58' 00.25" W

Right Monument Location (+/- 25'):
39° 35' 37.52" N
76° 58' 05.24" W
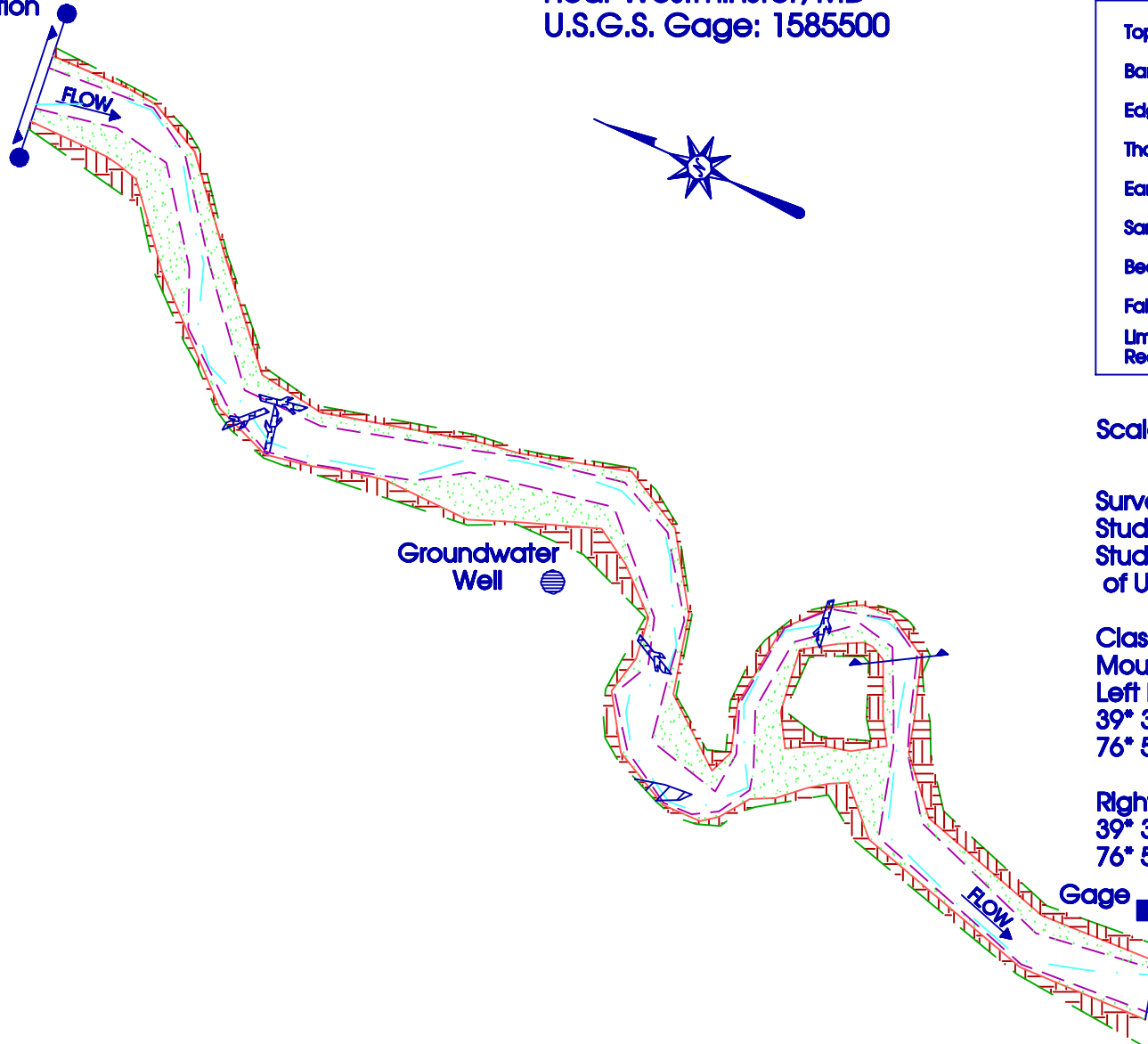
DEER CREEK AT ROCKS, MD
USGS STATION NUMBER: 1580000

Latitude:	39° 37' 49"	Gage Period of Record:	1926 - Present
Longitude:	76° 24' 13"	Mean Annual Discharge (cfs):	126.00
ADC Map Coordinates:	Harford / 1992	Rosgen Stream Type:	B4/1c
	Map 9 / H4	Survey Date:	Sept. 1997
Drainage Area (sq. mi.):	94.40		July 1998
Stream Order / Magnitude:	4 / 99		
Percent Imperviousness:	2.88		

Land Use (%): Residential: 6.94   Agricultural: 60.95   Forest: 30.69   Commercial: 1.14

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 1162.00 $Q_{1.5}$: 2850.00 $Q_{2.0}$: 3613.80
(Log-Pearson Period: 1927 - 1995)

General Study Reach Description: The study reach and the gage reach are the same. The reach has pool/riffle features, a fairly straight, bedrock-controlled meander pattern, poorly developed point- and sidebar depositional features, some lateral scour, and appears vertically stable with bedrock outcrops in the bed. There are several pieces of large woody debris, with one spanning the channel, and numerous boulders throughout the reach. At the upstream end of the reach, the channel is confined by a pair of old railroad bridge abutments. The bank vegetation is a mix of grass and moderately dense mature forest (hemlock, white pine, oak), with a moderately dense understory of mountain laurel.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	2614.00	Q_{bkf} / $Q_{2.0}$:	0.72	
Bankfull Return Interval (R.I.):	1.37	$Q_{Top of Bank}$(cfs):	3500.00	R.I.: 1.90
Gage Height (ft):	6.99	$Q_{Active Channel}$ (cfs):	605.00	R.I.:
Q_{bkf} / $Q_{1.5}$:	0.92			<1.005

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0021	Flood-prone Width (ft):	163.00
Manning's "n":	0.033	Entrenchment Ratio:	1.61
Mean Bankfull Velocity (ft/sec):	5.52	Width/Depth Ratio:	21.54
u/u*:	10.22	Channel Sinuosity:	1.22
R/D_{84}:	27.94	Beltwidth:	500
Froude Number:	0.45	Meander Width Ratio:	5.0

DEER CREEK AT ROCKS, MD
PARTICLE SIZE DISTRIBUTION
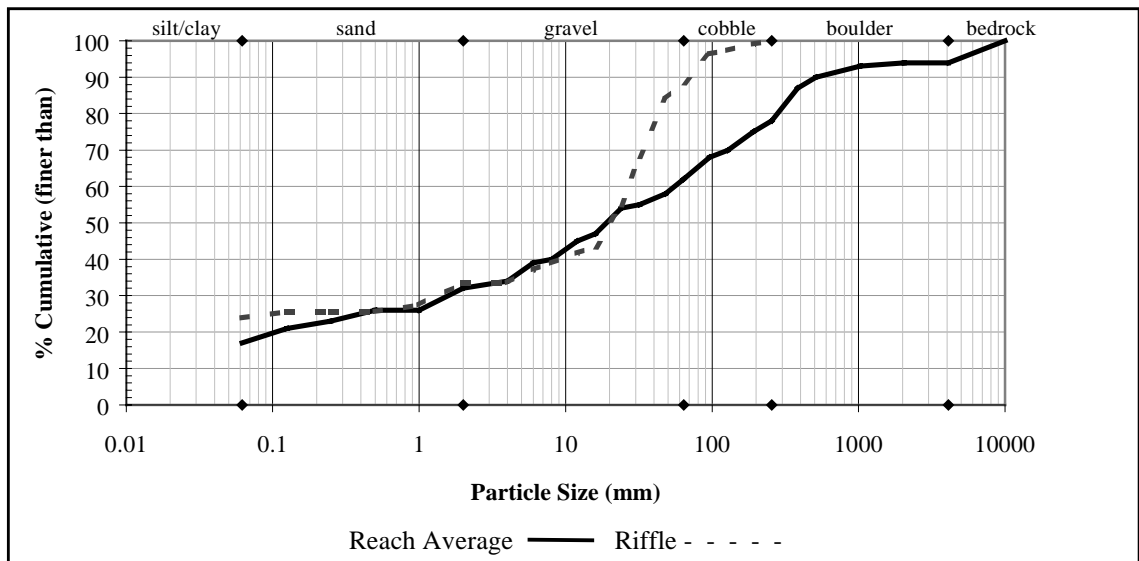
Particle Size (mm)		
Finer Than	Reach	Riffle
D_{16}	n/a	n/a
D_{35}	4.34	4.68
D_{50}	19.04	20.22
D_{84}	335.45	47.91
D_{95}	Bedrock	89.12

STUDY REACH CROSS SECTION
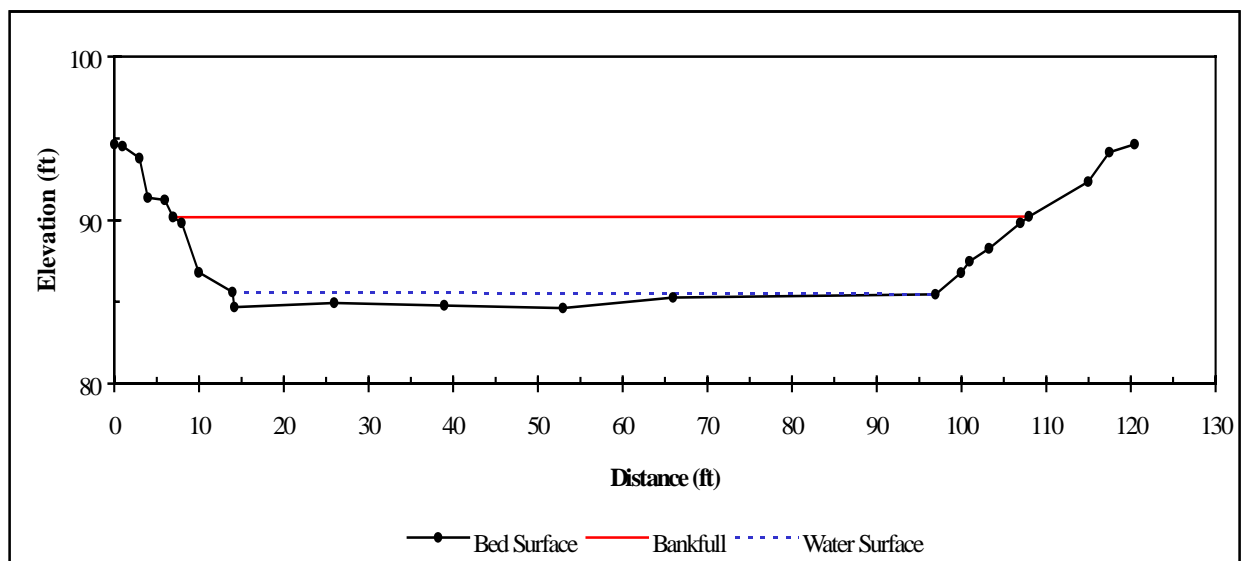
Bankfull Width (ft):	101.00	Mean Bankfull Depth (ft):	4.69
Bankfull Cross-sectional Area (ft^2):	473.67	Maximum Bankfull Depth (ft):	5.58
Hydraulic Radius (ft):	4.39	Wetted Perimeter (ft):	107.86

Deer Creek at Rocks, Maryland

Upstream view of classification cross-section


Right bank of classification cross-section

DEER CREEK
at Rocks, MD
U.S.G.S. Gage: 1580000

Old Bridge
Abutment

Old Bridge
Abutment

FLOW

LEGEND

Top of Bank :	— — —
Bankfull :	————
Edge of Water :	– – – –
Thalweg :	–·–·–
Earth :	▨▨▨
Sand/Gravel :	⣿⣿
Bed Rock :	▧▧▧
Boulders :	⬭⬭
Fallen Trees :	⋇
Limit of Study Reach:	▼——▼

Scale (ft):

| 0 | 50 | 100 | 200 |

Survey Date: 12/11/98
Study Reach Length: 1695'

FLOW

Rosgen Classification
Cross-Section

Study Reach Ends 435' D/S
at U.S.G.S. Gage (Not Surveyed)
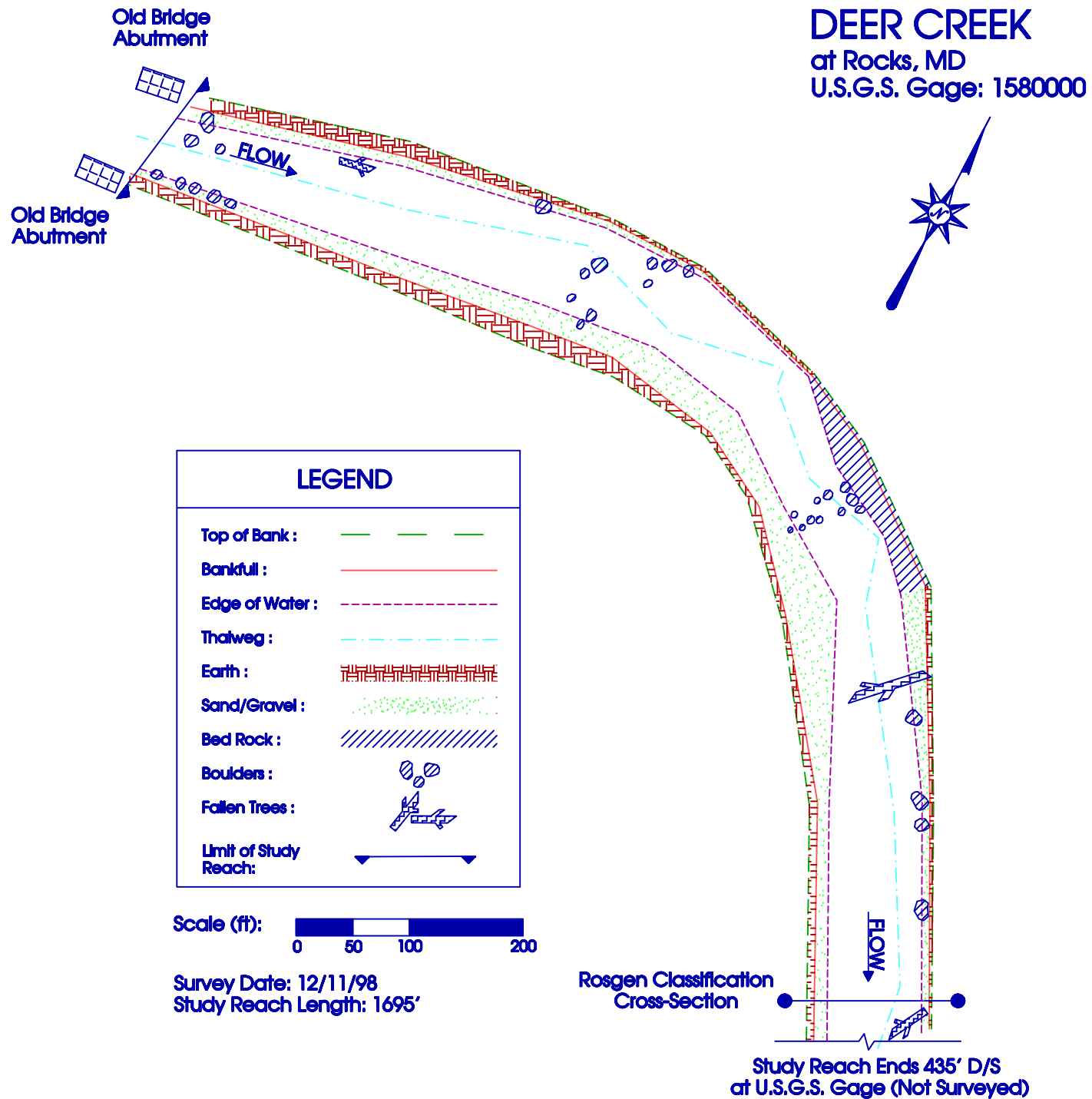
HAWLINGS RIVER NEAR SANDY SPRING, MD
USGS STATION NUMBER: 1591700

Latitude: 39° 10' 29"   Gage Period of Record: 1978 - Present
Longitude: 77° 01' 22"   Mean Annual Discharge (cfs):   30.70
ADC Map Coordinates: Montgomery / 1998   Rosgen Stream Type: C5
                              Map 22 / B3   Survey Date: Oct. 1997
Drainage Area (sq. mi.):   27.00   Jan. 1999
Stream Order / Magnitude: 4 / 50
Percent Imperviousness: 6.86

Land Use (%):   Residential: 17.83   Agricultural: 48.03   Forest: 28.32   Commercial: 1.84

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 185.40 $Q_{1.5}$: 940.00 $Q_{2.0}$: 1352.00
(Log Pearson Period: 1979 - 1998)

General Study Reach Description: The upstream end of the study reach is 638 feet downstream of the gage because the intervening riffle is unusually long and steep. The reach has pool/riffle features, a regular meander pattern with point-bar depositional features, some lateral scour, and appears vertically stable. There are numerous pieces of large woody debris, with several spanning the channel, resulting in one mid-channel bar. There is one bedrock outcrop. The bank vegetation is moderately dense forest, consisting of red maple and sycamore, with a moderately dense under-story of multiflora rose. The floodplain vegetation is a mix of forest and old-field, the latter predominantly multiflora rose.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):   1030.00 Q_{bkf} / $Q_{2.0}$:   0.76
Bankfull Return Interval (R.I.):   1.60 $Q_{Top of Bank}$(cfs):   1168.00   R.I.: 1.75
Gage Height (ft):   5.38 $Q_{Active Channel}$ (cfs):   n/a   R.I.: n/a
Q_{bkf} / $Q_{1.5}$:   1.10

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):   0.0022   Flood-prone Width (ft):   635.00
Manning's "n":   0.029   Entrenchment Ratio: 14.17
Mean Bankfull Velocity (ft/sec):   5.74   Width/Depth Ratio: 11.20
u/u^*:   11.25   Channel Sinuosity: 1.19
R/D_{84}:   31.14   Beltwidth: 102
Froude Number: 0.51   Meander Width Ratio: 2.3

HAWLINGS RIVER NEAR SANDY SPRING, MD
PARTICLE SIZE DISTRIBUTION
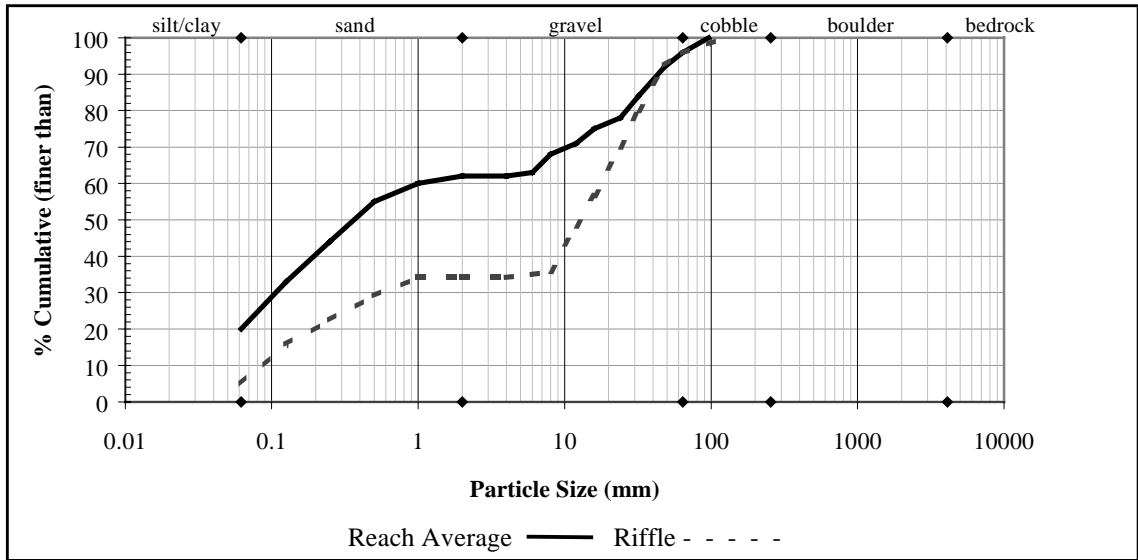
Particle Size (mm)		
Finer Than	Reach	Riffle
D 16	n/a	0.13
D 35	0.14	6.00
D 50	0.36	12.71
D 84	32.00	36.43
D 95	59.56	59.56

STUDY REACH CROSS SECTION
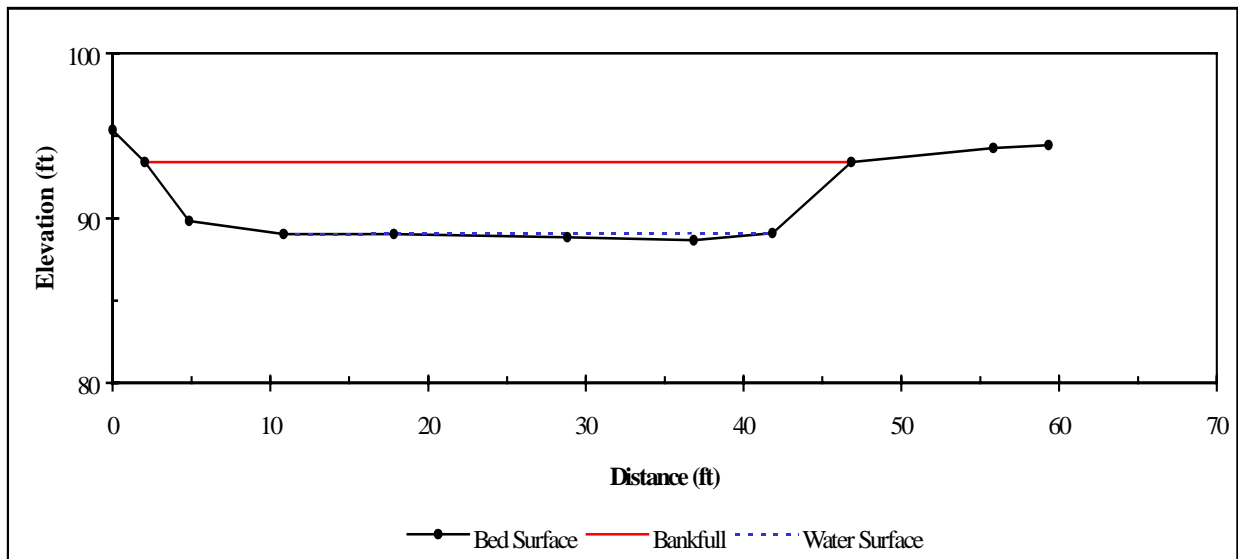
Bankfull Width (ft):	44.80	Mean Bankfull Depth (ft):	4.00
Bankfull Cross-sectional Area (ft^2):	179.31	Maximum Bankfull Depth (ft):	4.74
Hydraulic Radius (ft):	3.72	Wetted Perimeter (ft):	48.21

Hawlings River near Sandy Springs, Maryland

Downstream view of classification cross-section

Right bank of classification cross-section

HAWLINGS RIVER
near Sandy Springs, MD
U.S.G.S. Gage: 1591700

FLOW

Electrical Power Line
ROW

Rosgen Classification
Cross-Section

FLOW

LEGEND

Top of Bank :	
Bankfull :	
Edge of Water :	
Thalweg :	
Earth :	
Sand/Gravel :	
Boulders :	
Fallen Trees :	
Limit of Study Reach:	

Scale (ft):

0   50   100   200

Survey Dates: 1/13/99 & 1/14/99
Study Reach Length: 1545'
Study Reach: 638' D/S of U.S.G.S. Gage
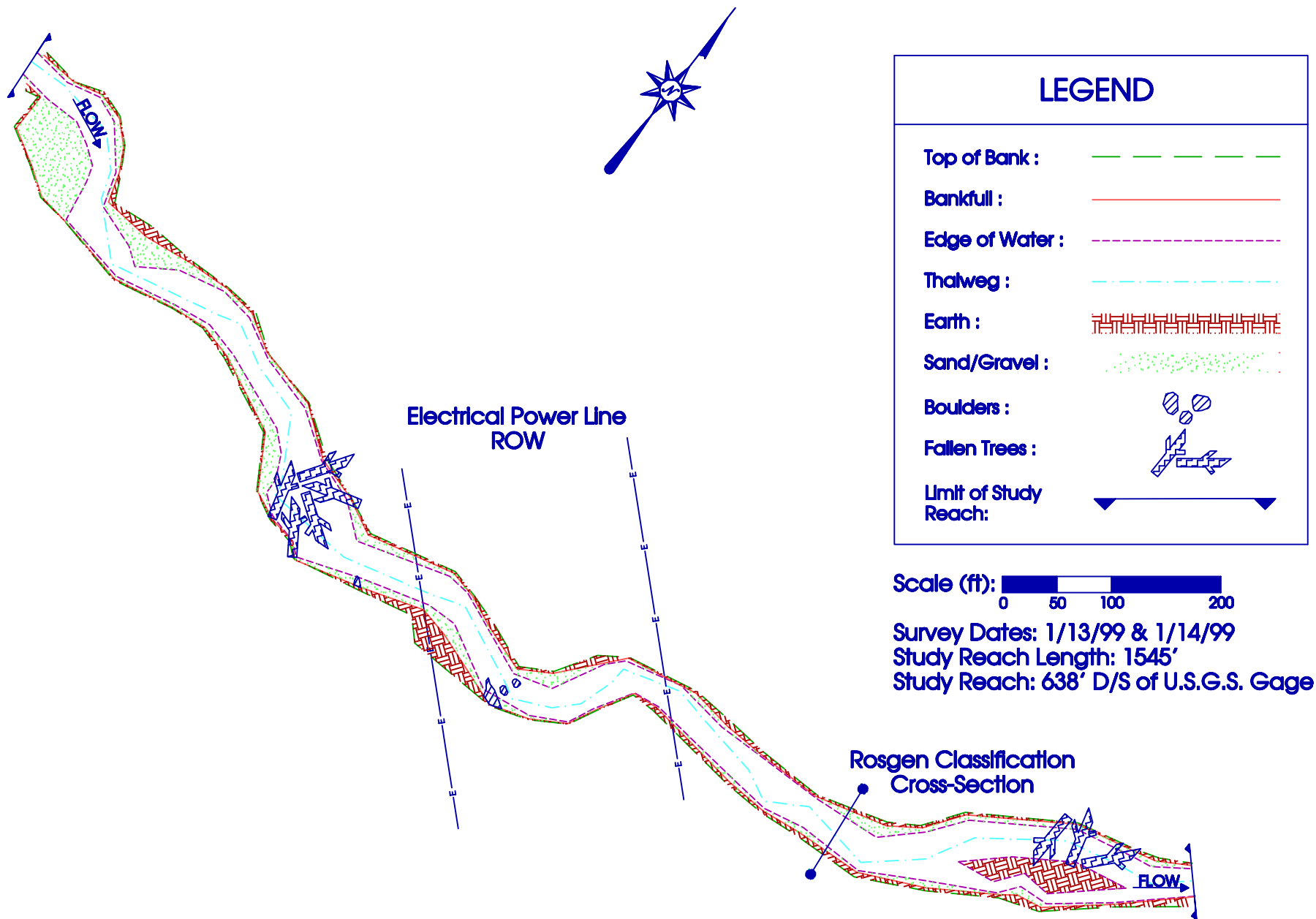
JONES FALLS AT SORRENTO, MD
USGS STATION NUMBER: 1589440

Latitude:	39° 23' 30"	Gage Period of Record:	1966 – 1988
Longitude:	76° 39' 42"		1996 - Present
ADC Map Coordinates:	Baltimore / 1993	Mean Annual Discharge (cfs):	32.50
	Map 26 / E7-8	Rosgen Stream Type:	C4
Drainage Area (sq. mi.):	25.20	Survey Date:	Oct. 1998
Stream Order / Magnitude:	3 / 25		Jan. 1999
Percent Imperviousness:	21.43		

Land Use (%):   Residential: 46.84   Agricultural: 19.54   Forest: 24.82   Commercial: 7.23

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 250.60 $Q_{1.5}$: 840.00 $Q_{2.0}$: 1190.00
(Log-Pearson Period: 1975 - 1998)

General Study Reach Description: The study reach and gage reach are the same. The reach has pool/riffle features, a straight meander pattern with point- and side-bar depositional features, and some lateral scour. A sanitary sewer pipe has been exposed downstream of the gage. The channel appears altered and may have been straightened in the past due to construction of Falls Road. The bank and floodplain vegetation is moderately dense mature forest with a moderately dense understory of sapling trees and shrubs.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	914.70	Q_{bkf} / $Q_{2.0}$:	0.77	
Bankfull Return Interval (R.I.):	1.57	$Q_{Top of Bank}$(cfs):	1137.00	R.I.: 2.00
Gage Height (ft):	7.32	$Q_{Active Channel}$ (cfs):	581.60	R.I.: 1.20
Q_{bkf} / $Q_{1.5}$:	1.09			

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0016	Flood-prone Width (ft):	196.00
Manning's "n":	0.027	Entrenchment Ratio:	3.63
Mean Bankfull Velocity (ft/sec):	4.93	Width/Depth Ratio:	15.74
u/u*:	12.02	Channel Sinuosity:	1.13
R/D$_{84}$:	59.46	Beltwidth:	
Froude Number:	0.47	Meander Width Ratio:	1.9

JONES FALLS AT SORRENTO, MD
PARTICLE SIZE DISTRIBUTION
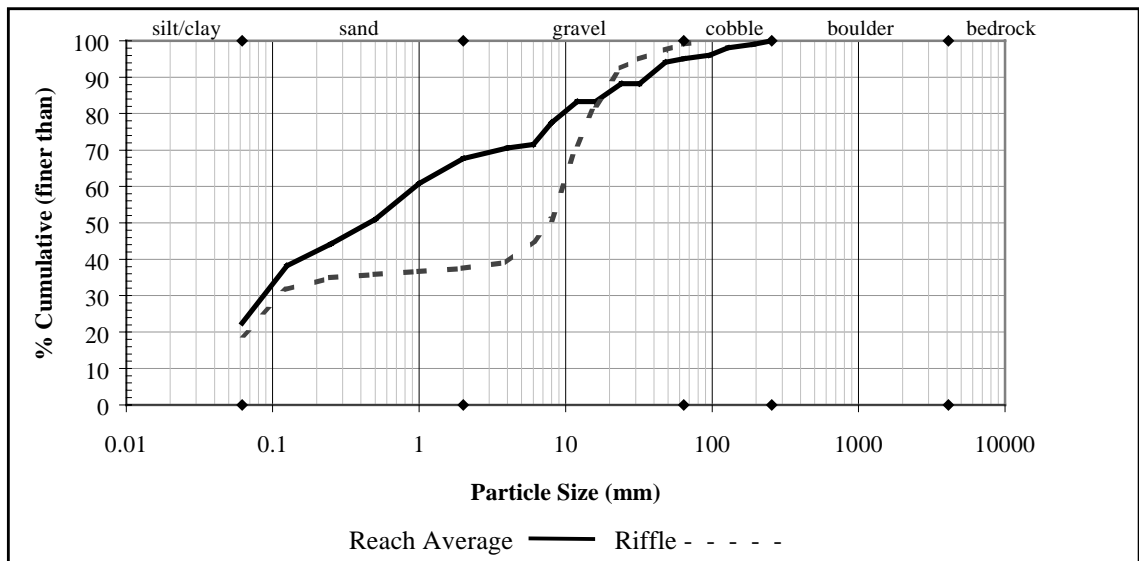
Particle Size (mm)		
Finer Than	Reach	Riffle
D_{16}	n/a	n/a
D_{35}	0.11	0.30
D_{50}	0.45	7.70
D_{84}	16.91	17.00
D_{95}	62.19	32.00

The reach pebble count distribution is bi-modal (sand and gravel). The largest number of oberservations is in the gravel size class. The riffle pebble count D_{50} is gravel.

STUDY REACH CROSS SECTION
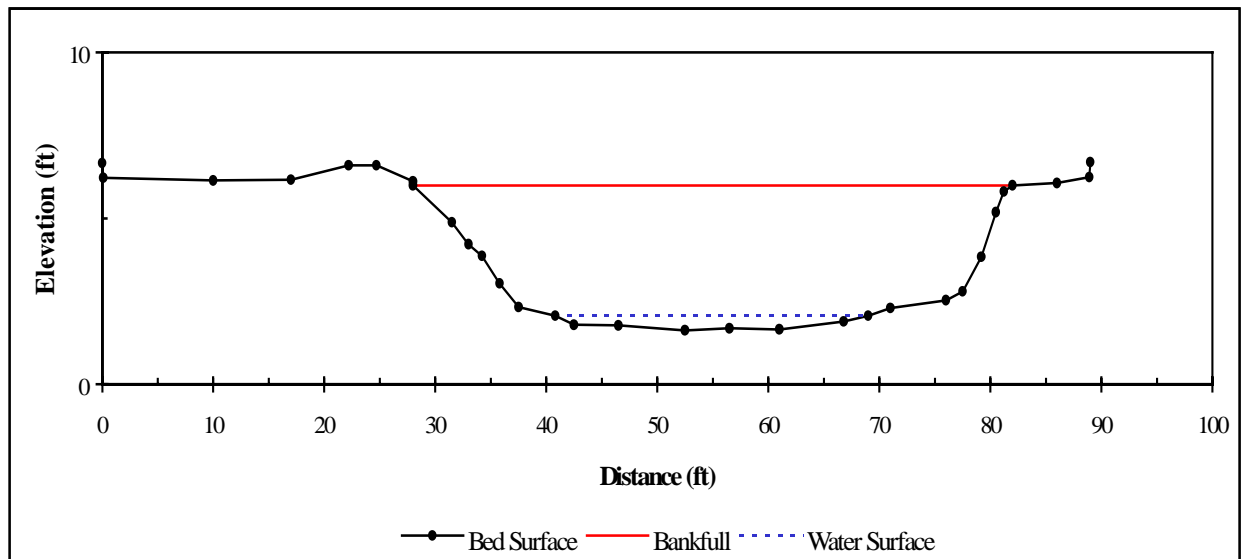
Bankfull Width (ft):	54.00	Mean Bankfull Depth (ft):	3.43
Bankfull Cross-sectional Area (ft²):	185.45	Maximum Bankfull Depth (ft):	4.36
Hydraulic Radius (ft):	3.32	Wetted Perimeter (ft):	55.92

Jones Falls at Sorrento, Maryland

Downstream view of classification cross-section

Left bank of classification cross-section

JONES FALLS
at Sorrento, MD
U.S.G.S. Gage:1589440
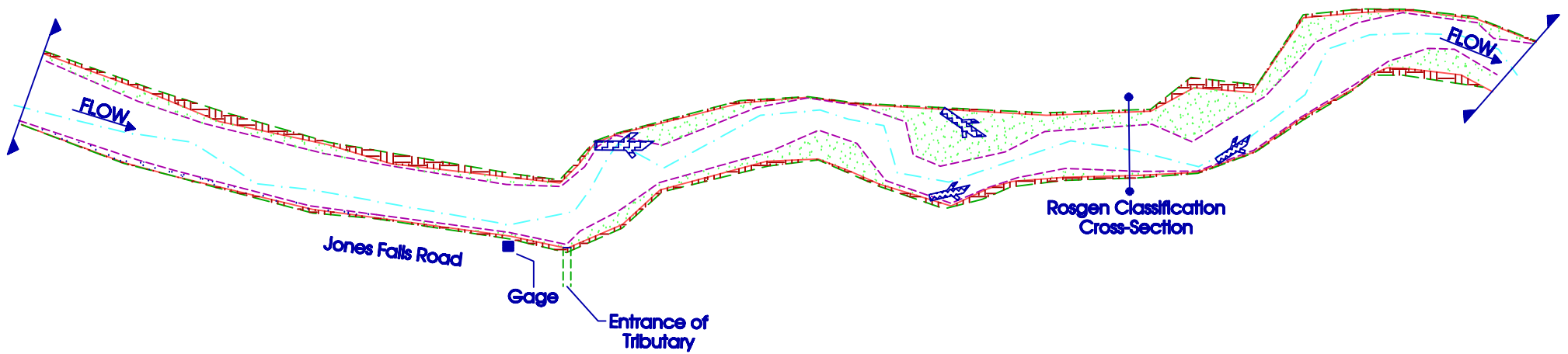
FLOW

FLOW

FLOW

Jones Falls Road

Gage

Entrance of
Tributary

Rosgen Classification
Cross-Section

LEGEND	
Top of Bank :	– – – – –
Bankfull :	————
Edge of Water :	– – – – –
Thalweg :	–·–·–·–
Earth :	
Sand/Gravel :	
Fallen Trees :	
Limit of Study Reach:	▼ ▼

Scale (ft):

0   50   100   200

Survey Dates: 1/5/99 & 1/6/99
Study Reach Length 1308'

Classification Cross-Section Monument Locations:
Left Monument Location (+/- 15):
39° 23' 26.07" N
79° 39' 35.37" W
Elevation: 284'

Right Monument Location (+/- 15):
39° 23' 25.32" N
76° 39' 36.54" W
Elevation: 246'

LITTLE FALLS AT BLUE MOUNT, MD
USGS STATION NUMBER: 1582000

Latitude:	39° 36' 16"	Gage Period of Record:	1944 - Present
Longitude:	76° 37' 16"	Mean Annual Discharge (cfs):	68.60
ADC Map Coordinates:	Baltimore / 1993	Rosgen Stream Type:	C4
	Map 8 / A8	Survey Date:	Oct. 1997
Drainage Area (sq. mi.):	52.90		Dec. 1998
Stream Order / Magnitude:	4 / 68		
Percent Imperviousness:	2.77		

Land Use (%):   Residential: 8.24   Agricultural: 53.14   Forest: 37.00   Commercial: 0.76

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 524.4 (sys) $Q_{1.5}$: 1750.00 $Q_{2.0}$: 2230.00
(Log-Pearson Period: 1945 - 2000)

General Study Reach Description: The downstream end of the study reach is 450 feet upstream of the gage because the intervening reach exhibits aggradation and lateral adjustment. The study reach has pool/riffle features, a regular, bedrock-controlled meander pattern with point and side bar depositional features, and some lateral scour. Several pieces of large woody debris are in the reach, but none span the channel, although one is causing some mid-channel aggradation through a riffle. The bank and floodplain vegetation is moderately dense forest, consisting of oak, red maple and sycamore. The forest is mature on the right bank, but relatively young on the left. The understory on both sides is a low-density mix of sapling trees and shrubs. The channel is bordered on the left by a maintained trail on a railroad bed that crosses the channel at the upstream end and at the gage.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	1674.00	Q_{bkf} / $Q_{2.0}$:	0.75	
Bankfull Return Interval (R.I.):	1.45	$Q_{Top\ of\ Bank}$(cfs):	3161.00	R.I.: 4.00
Gage Height (ft):	5.47	$Q_{Active\ Channel}$ (cfs):	851.10	R.I.:1.03
Q_{bkf} / $Q_{1.5}$:	0.96			(SYS)

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0019	Flood-prone Width (ft):	313.50
Manning's "n":	0.036	Entrenchment Ratio:	4.61
Mean Bankfull Velocity (ft/sec):	4.99	Width/Depth Ratio:	13.79
u/u*:	9.42	Channel Sinuosity:	1.09
R/D_{84}:	20.12	Beltwidth:	204
Froude Number:	0.40	Meander Width Ratio:	3.0

LITTLE FALLS AT BLUE MOUNT, MD
PARTICLE SIZE DISTRIBUTION
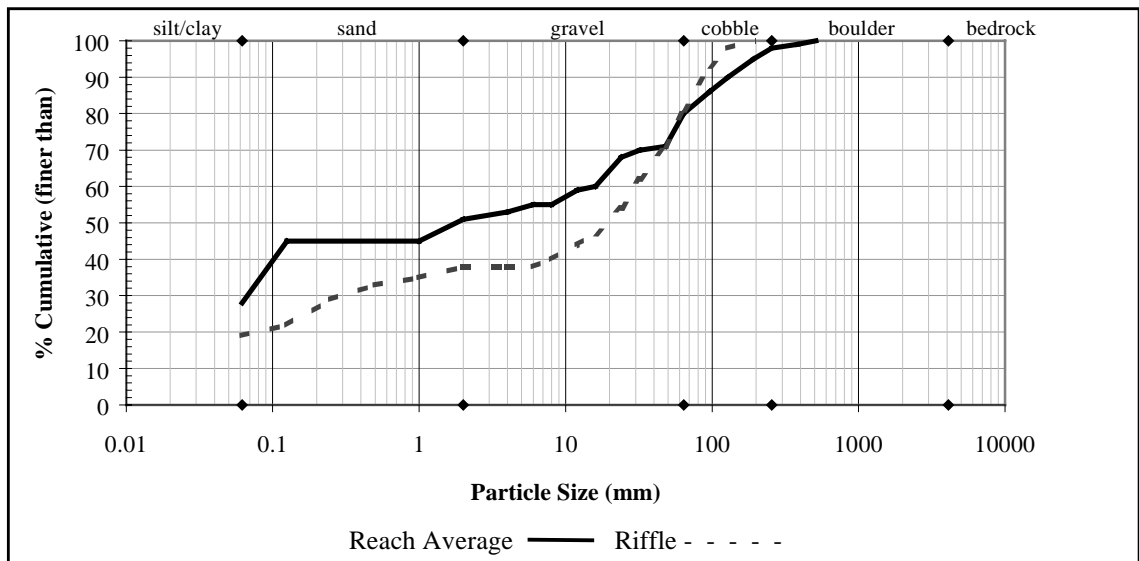
Particle Size (mm)		
Finer Than	Reach	Riffle
D_{16}	n/a	n/a
D_{35}	0.08	1.09
D_{50}	1.74	18.73
D_{84}	82.96	70.40
D_{95}	192.00	108.82

The reach pebble count distribution is bi-modal (silt/clay and gravel). The largest number of oberservations is in the gravel size class. The riffle pebble count D_{50} is gravel.

STUDY REACH CROSS SECTION
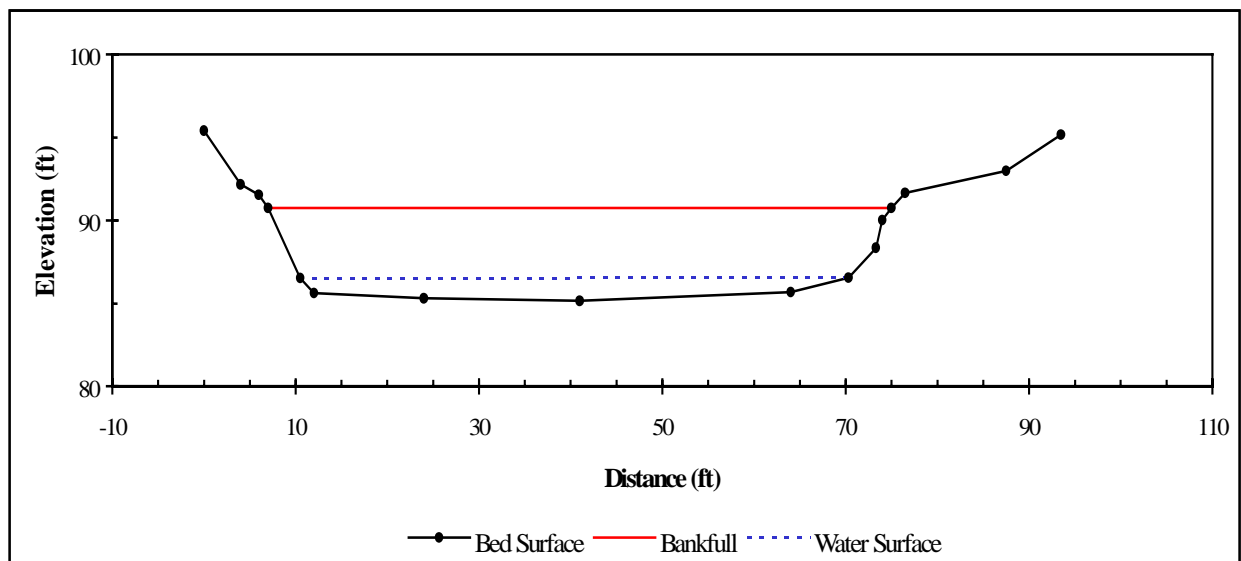
Bankfull Width (ft):	68.00	Mean Bankfull Depth (ft):	4.93
Bankfull Cross-sectional Area (ft^2):	335.26	Maximum Bankfull Depth (ft):	5.60
Hydraulic Radius (ft):	4.65	Wetted Perimeter (ft):	72.16

Little Falls at Blue Mount, Maryland

Downstream view of classification cross-section

Right bank of classification cross-section

LITTLE FALLS
at Blue Mount, MD
U.S.G.S. Gage:1582000
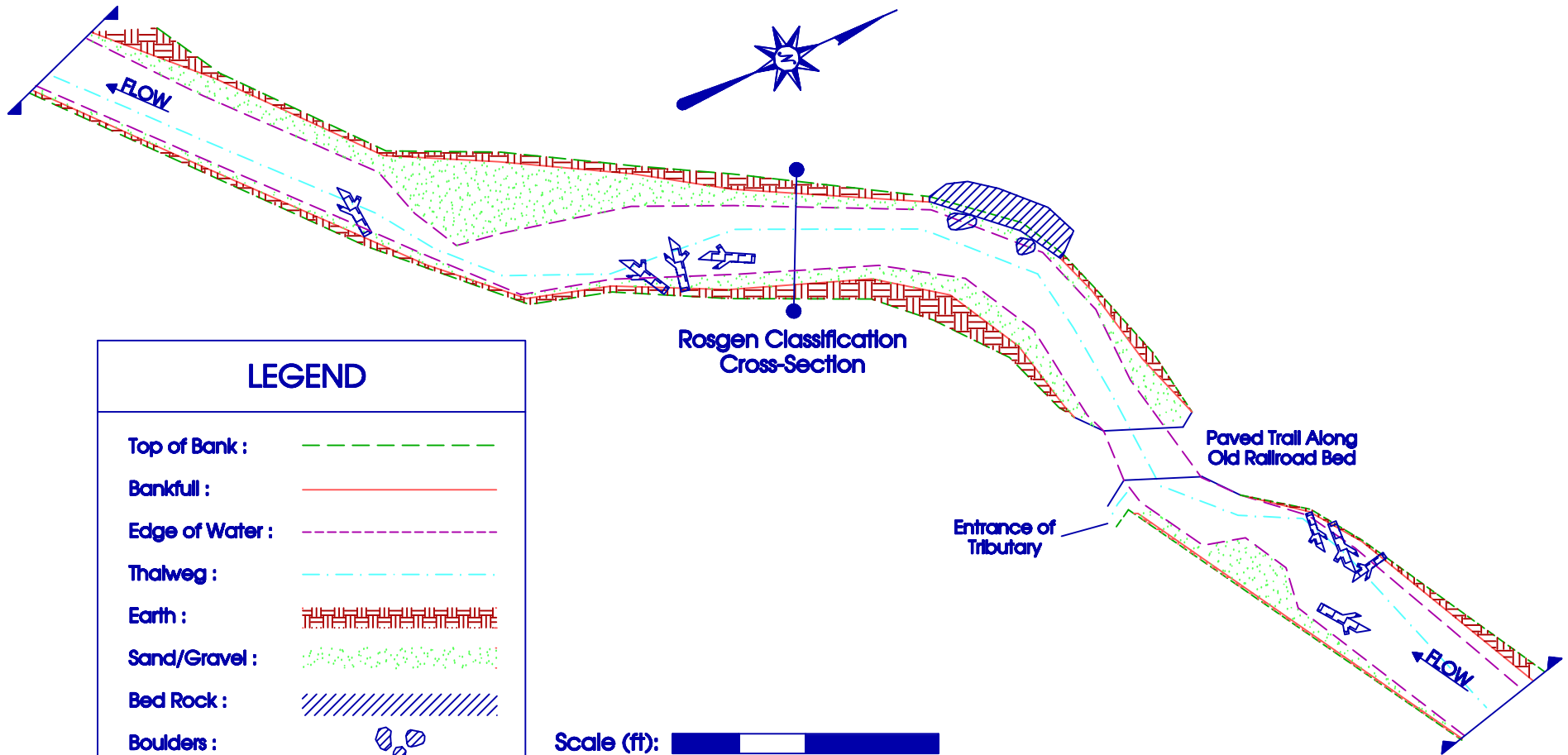
FLOW

N

Rosgen Classification
Cross-Section

Paved Trail Along
Old Railroad Bed

Entrance of
Tributary

FLOW

LEGEND

Top of Bank :	
Bankfull :	
Edge of Water :	
Thalweg :	
Earth :	
Sand/Gravel :	
Bed Rock :	
Boulders :	
Fallen Trees :	
Limit of Study Reach:	

Scale (ft):

0   50   100   200

Survey Date: 12/21/98
Study Reach Length: 1278'
Study Reach: 450' U/S of U.S.G.S. Gage

LITTLE PATUXENT RIVER AT GUILFORD
USGS STATION NUMBER: 1593500

Latitude:	39° 10' 04"	Gage Period of Record:	1932 - Present
Longitude:	76° 51' 07"	Mean Annual Discharge (cfs):	43.90
ADC Map Coordinates:	Howard / 1992	Rosgen Stream Type:	E5
	Map 19 / H-J2	Survey Date:	Oct. 1997
Drainage Area (sq. mi.):	38.00		Dec. 1998
Stream Order / Magnitude:	4 / 99		Oct. 2000
Percent Imperviousness:	18.48		

Land Use (%):   Residential: 33.40   Agricultural: 25.03   Forest: 30.95   Commercial: 7.33

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 444.50 $Q_{1.5}$: 1050.00 $Q_{2.0}$: 1362.60
(Log-Pearson Period: 1933 - 1995)

General Study Reach Description: The study reach and the gage reach are the same. The reach has pool/riffle features, a regular meander pattern with few point bar depositional features, some lateral scour, and appears vertically stable. There are numerous pieces of large woody debris in the middle of the reach, with several pieces extending well into the channel. The lower end of the reach is stabilized on the right bank by boulder revetment associated with Guilford Road. The bank and floodplain vegetation is moderately dense forest, consisting of green ash, red maple, oak and sycamore, with a moderately dense understory of sapling trees and shrubs.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	1024.00	Q_{bkf} / $Q_{2.0}$:	0.75		
Bankfull Return Interval (R.I.):	1.48	$Q_{Top of Bank}$(cfs):	1435.00	R.I.: 2.20
Gage Height (ft):	7.10	$Q_{Active Channel}$ (cfs):	n/a	R.I.: n/a
Q_{bkf} / $Q_{1.5}$:	0.98				

STUDY REACH SURVEY INFORMATION

Average Bankfull Slope (ft/ft):	0.0005	Flood-prone Width (ft):	478.00
Manning's "n":	0.022	Entrenchment Ratio:	9.60
Mean Bankfull Velocity (ft/sec):	4.08	Width/Depth Ratio:	9.88
u/u*:	15.11	Channel Sinuosity:	1.37
R/D_{84}:	172.53	Beltwidth:	266
Froude Number:	0.32	Meander Width Ratio:	5.3

LITTLE PATUXENT RIVER AT GUILFORD
PARTICLE SIZE DISTRIBUTION
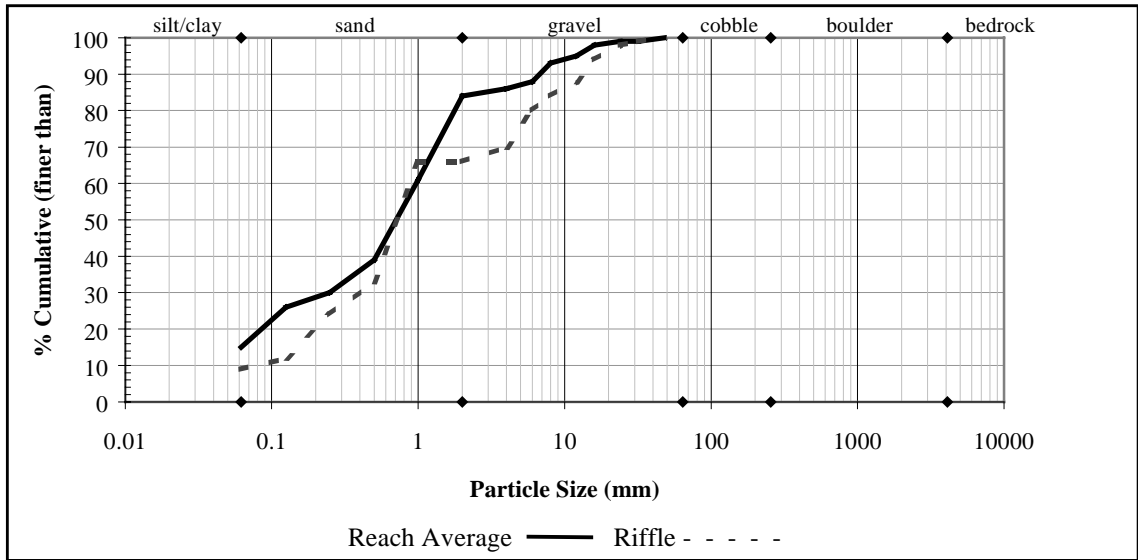
Particle Size (mm)		
Finer Than	Reach	Riffle
D $_{16}$	0.07	0.16
D $_{35}$	0.37	0.52
D $_{50}$	0.71	0.71
D $_{84}$	2.00	8.00
D $_{95}$	12.00	17.71

STUDY REACH CROSS SECTION
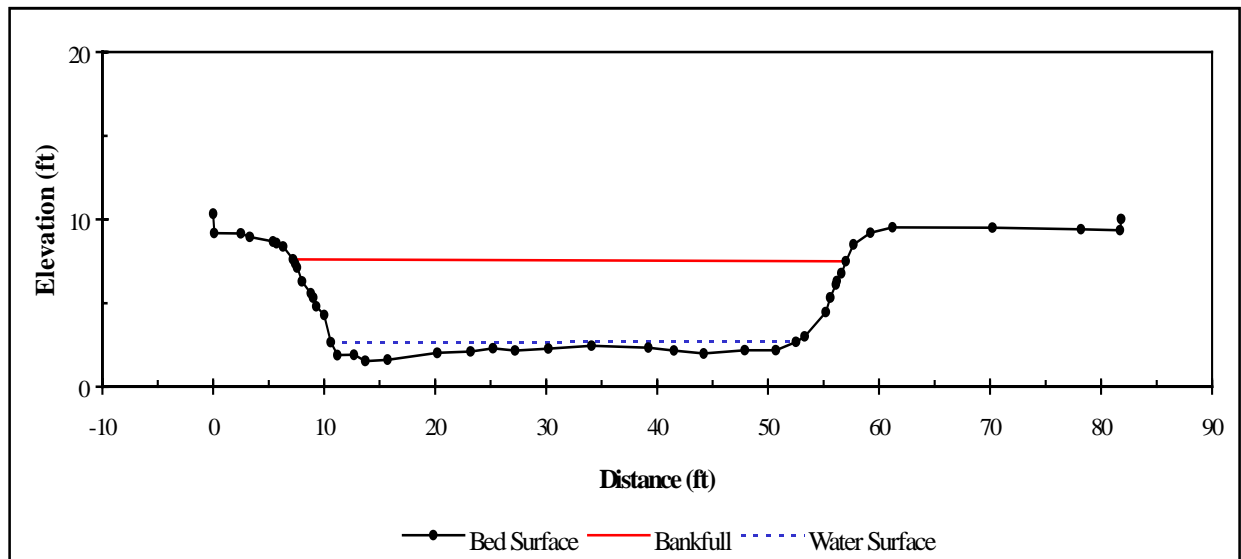
Bankfull Width (ft):	49.80	Mean Bankfull Depth (ft):	5.04
Bankfull Cross-sectional Area (ft^2):	251.05	Maximum Bankfull Depth (ft):	6.08
Hydraulic Radius (ft):	4.53	Wetted Perimeter (ft):	55.44

Little Patuxent River at Guilford, Maryland

Upstream view of classification cross-section

Right bank of classification cross-section

LITTLE PATUXENT RIVER
at Guilford, MD
U.S.G.S. Gage: 1593500

Broken Land Parkway (Approximate Location)

FLOW
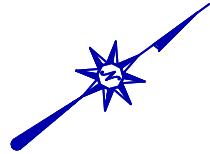
Rosgen Classification
Cross-Section ●

● Entrance of
Tributary

Guilford Road (Approximate Location)

FLOW

Study Reach Ends
60' d/s at U.S.G.S.
Gage Weir
(Not Surveyed)

Gage House
(Approximate Location)

Scale (ft):

| 0 | 50 | 100 | 200 |

Survey Date: 12/16/98
Study Reach Length: 1159'

LEGEND

Top of Bank :	– – – – –
Bankfull :	————
Edge of Water :	– – – – –
Thalweg :	–·–·–·–
Earth :	▦▦▦▦
Sand/Gravel :	░░░░
Boulders :	⬭⬮
Fallen Trees :	✴✴
Rubble Rip-Rap:	△ △ △ △ △ △ △△
Limit of Study Reach:	◄————►
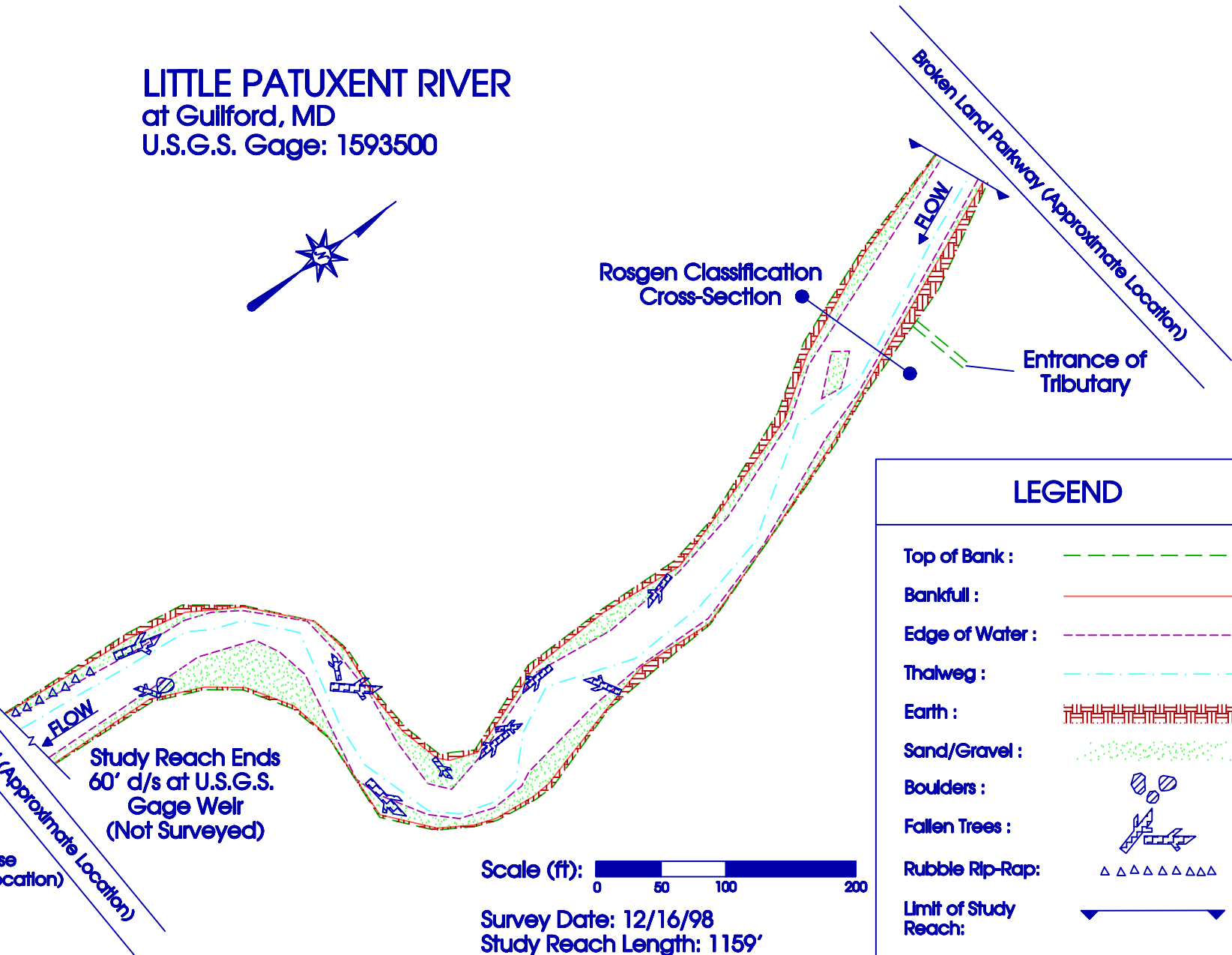
LONG GREEN CREEK AT GLEN ARM, MD
USGS STATION NUMBER: 1584050

Latitude:	39° 27' 17"	Gage Period of Record:	1975 - Present
Longitude:	76° 28' 45"	Mean Annual Discharge (cfs):	11.50
ADC Map Coordinates:	Baltimore / 1993	Rosgen Stream Type:	C2/1
	Map 21 / B-C10	Survey Date:	Oct. 1997
Drainage Area (sq. mi.):	9.40		Feb. 1999
Stream Order / Magnitude:	3 / 18		Aug. 2000
Percent Imperviousness:	12.36		

Land Use (%):   Residential: 18.82   Agricultural: 52.57   Forest: 19.31   Commercial: 9.02

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 85.20 $Q_{1.5}$: 460.00 $Q_{2.0}$: 690.20
(Log-Pearson Period: 1976 - 1994)

General Study Reach Description: The upstream end of the study reach is 507 feet downstream of the gage. The reach has cascade features, a relatively straight boulder-controlled meander pattern with no depositional features, and appears vertically stable. There is no large woody debris, but large boulders are abundant and distributed throughout the reach. Upstream of the private road crossing, the right bank and floodplain vegetation is grass lawn, while the left bank has young trees and shrubs with little or no floodplain due to encroachment by the road. Downstream of the bridge, the bank and floodplain vegetation on both sides is moderately dense forest, consisting of green ash, holly, tulip, poplar, and walnut with a moderately dense understory consisting mostly of multiflora rose and privet.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	365.10	Q_{bkf} / $Q_{2.0}$:	0.53	
Bankfull Return Interval (R.I.):	1.32	$Q_{Top of Bank}$(cfs):	> 3250	R.I.: >15
Gage Height (ft):	3.70	$Q_{Active Channel}$ (cfs):	110.30	R.I.: 1.02
Q_{bkf} / $Q_{1.5}$:	0.79			

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0165	Flood-prone Width (ft):	184.00
Manning's "n":	0.064	Entrenchment Ratio:	4.22
Mean Bankfull Velocity (ft/sec):	4.40	Width/Depth Ratio:	22.95
u/u*:	4.53	Channel Sinuosity:	1.04
R/D$_{84}$:	1.75	Beltwidth:	46
Froude Number:	0.56	Meander Width Ratio:	1.1

LONG GREEN CREEK AT GLEN ARM, MD
PARTICLE SIZE DISTRIBUTION
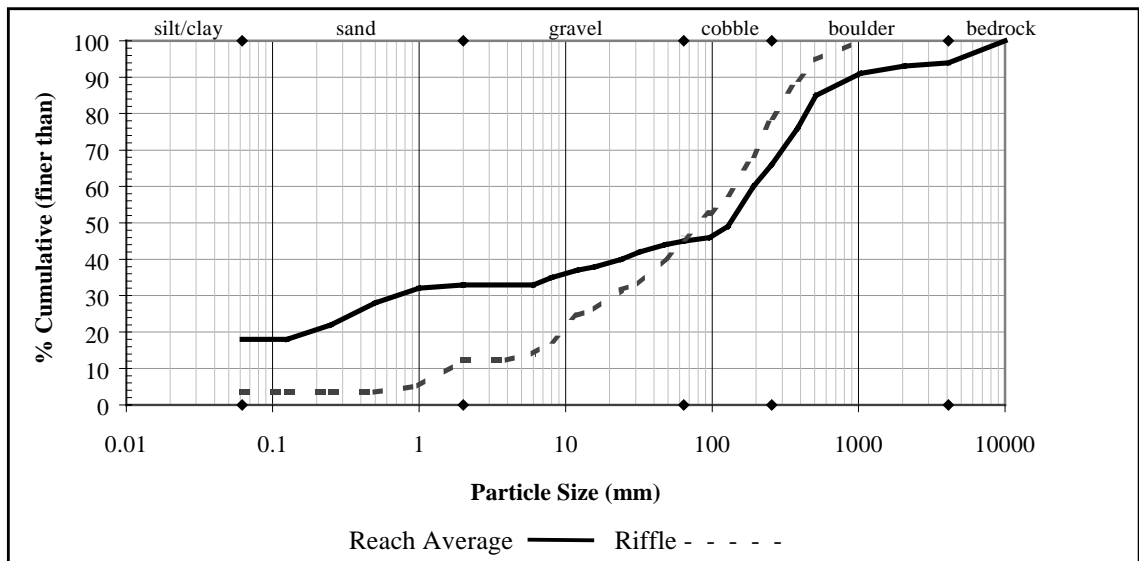
Particle Size (mm)		
Finer Than	Reach	Riffle
D$_{16}$	n/a	7.05
D$_{35}$	8.00	35.23
D$_{50}$	132.81	82.46
D$_{84}$	495.89	311.00
D$_{95}$	Bedrock	530.06

The reach pebble count distribution is bi-modal (silt and boulder). The largest number of observations is in the boulder size class. The riffle pebble count D$_{50}$ is cobble.

STUDY REACH CROSS SECTION
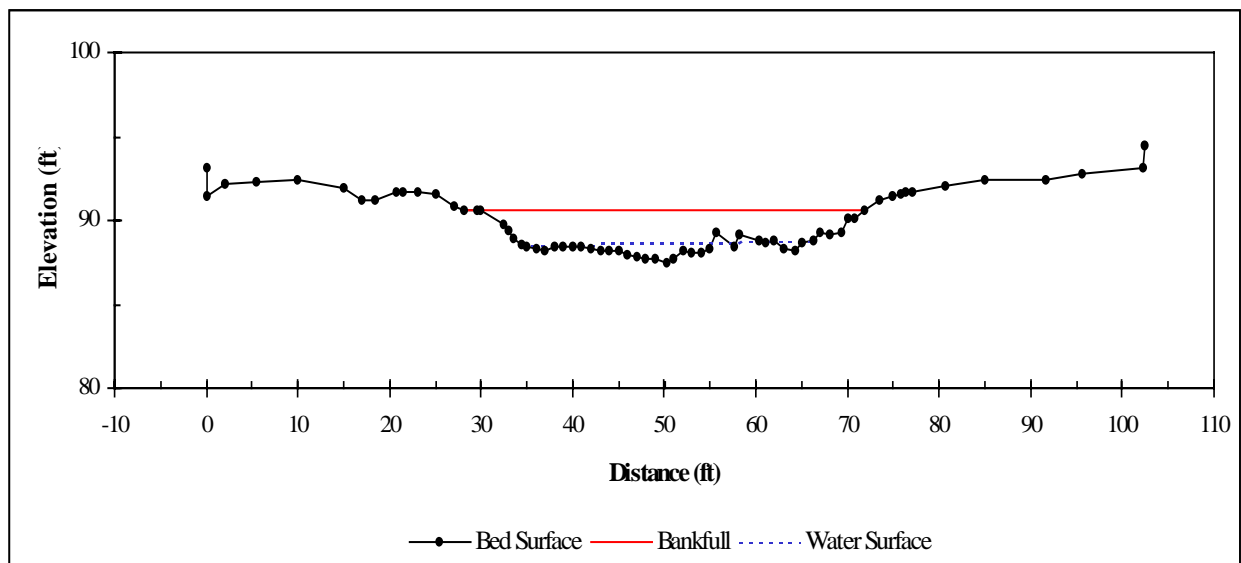
Bankfull Width (ft):	43.60	Mean Bankfull Depth (ft):	1.90
Bankfull Cross-sectional Area (ft^2):	82.93	Maximum Bankfull Depth (ft):	3.12
Hydraulic Radius (ft):	1.78	Wetted Perimeter (ft):	46.47

Long Green Creek at Glen Arm, Maryland

Upstream view of classification cross-section

Right bank of classification cross-section

LONG GREEN CREEK
at Glen Arm, MD
U.S.G.S. Gage: 1584050

Rosgen Classification
Cross-Section

FLOW

Entrance of Small
Tributary

FLOW

HILLRISE
ROAD
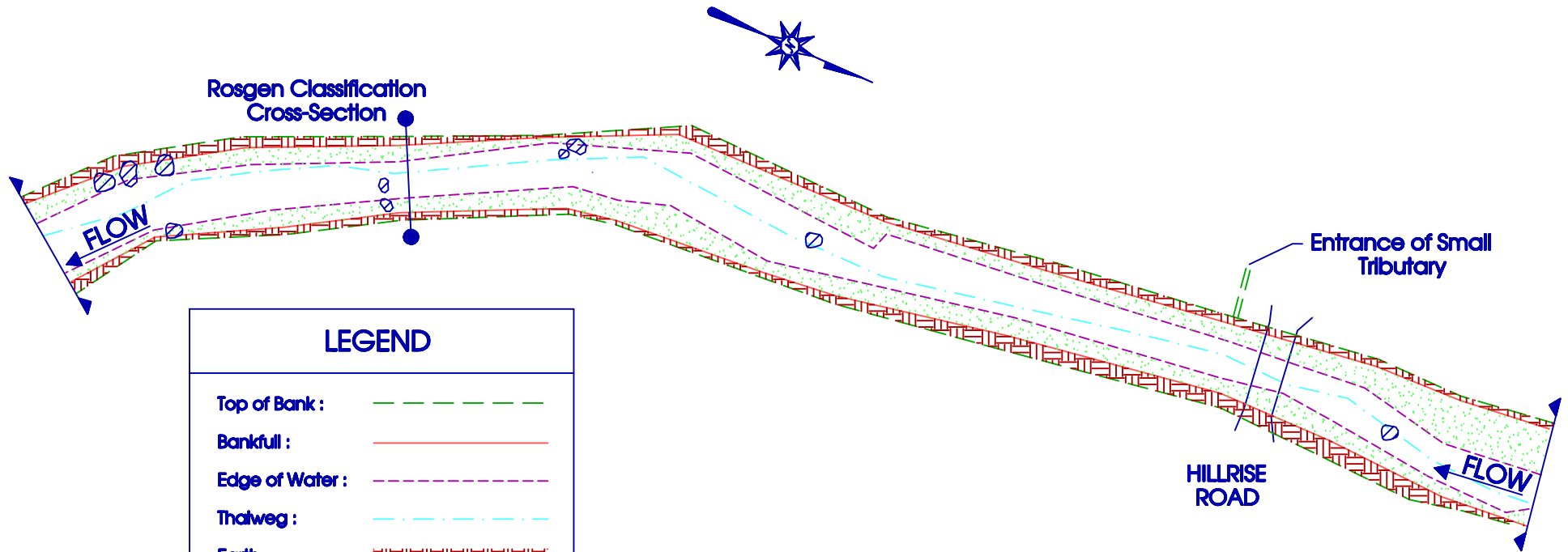
LEGEND

Top of Bank :	– – – –
Bankfull :	———
Edge of Water :	– – – –
Thalweg :	–·–·–
Earth :	▨▨▨
Sand/Gravel :	░░░
Boulders :	⬭⬭
Limit of Study Reach:	▼——▼

Scale (ft):

0   50   100   200

Survey Date: 2/19/99
Study Reach Length: 994'
Study Reach 507' D/S of U.S.G.S. Gage

Classification Cross-Section Monument Locations:
Left Monument Location (+/- N/A)   Right Monument Location (+/- 20'):
N/A   39°27'3.08" N
N/A   76°28'37.26" W
Elev. N/A   Elev. 277'

MORGAN RUN AT LOUISVILLE, MD
USGS STATION NUMBER: 1586610

Latitude:	39° 27' 07"	Gage Period of Record:	1982 – Present
Longitude:	76° 57' 20"	Mean Annual Discharge (cfs):	35.00
ADC Map Coordinates:	Carroll / 1990	Rosgen Stream Type:	C4/1
	Map 30 / C1	Survey Date:	Oct. 1997
Drainage Area (sq. mi.):	28.00		Sept. 1998
Stream Order / Magnitude:	5 / 65		
Percent Imperviousness:	4.00		

Land Use (%):   Residential: 14.73   Agricultural: 53.52   Forest: 31.20   Commercial: 0.34

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 235.70 $Q_{1.5}$: 850.00 $Q_{2.0}$: 1170.00
(Log-Pearson Period: 1983 - 2000)

General Study Reach Description: The downstream end of the study reach is 322 feet upstream of the gage due to deposition and lateral adjustment from the bridge crossing in the intervening reach. The study reach has pool/riffle features, a bedrock-controlled meander pattern, point and side bar depositional features, some lateral scour, and appears vertically stable. There are several pieces of large woody debris; two extend well into the channel. Numerous boulders and bedrock outcrops occur throughout the reach. The bank and floodplain vegetation is moderately dense forest, consisting of oak, sycamore, tulip poplar, and walnut, with a moderately dense understory, consisting of ironwood and mountain laurel.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	1024.00	$Q_{bkf} / Q_{2.0}$:	0.88	
Bankfull Return Interval (R.I.):	1.75	$Q_{Top of Bank}$(cfs):	2233.00	R.I.: 5.00
Gage Height (ft):	4.82	$Q_{Active Channel}$ (cfs):	238.30	R.I.: 1.01
$Q_{bkf} / Q_{1.5}$:	1.20			(SYS)

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0052	Flood-prone Width (ft):	178.00
Manning's "n":	0.037	Entrenchment Ratio:	3.42
Mean Bankfull Velocity (ft/sec):	6.18	Width/Depth Ratio:	16.35
u/u*:	8.58	Channel Sinuosity:	1.18
R/D_{84}:	4.41	Beltwidth:	314
Froude Number:	0.61	Meander Width Ratio:	6.0

MORGAN RUN AT LOUISVILLE, MD
PARTICLE SIZE DISTRIBUTION
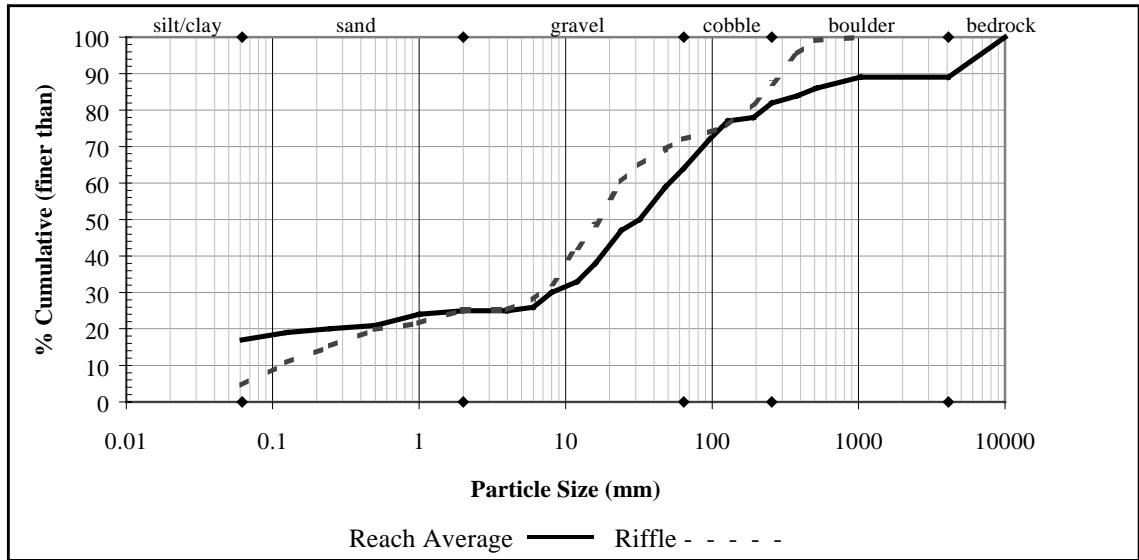
Particle Size (mm)		
Finer Than	Reach	Riffle
D 16	n/a	0.28
D 35	13.46	8.89
D 50	32.00	16.77
D 84	384.00	213.77
D 95	Bedrock	374.60

STUDY REACH CROSS SECTION
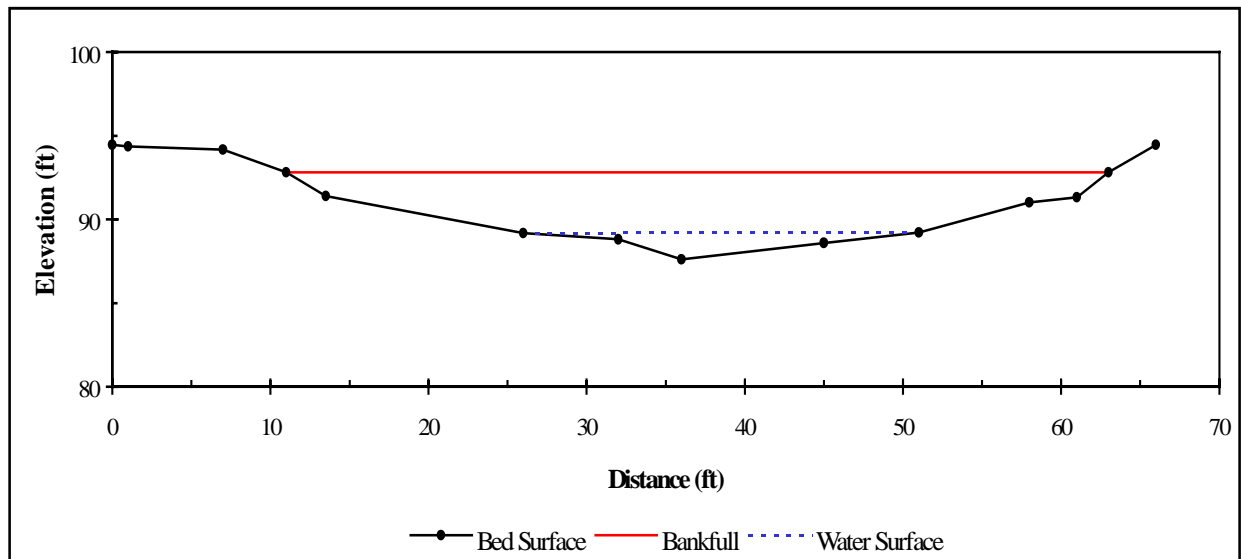
Bankfull Width (ft):	52.00	Mean Bankfull Depth (ft):	3.18
Bankfull Cross-sectional Area (ft^2):	165.58	Maximum Bankfull Depth (ft):	5.20
Hydraulic Radius (ft):	3.09	Wetted Perimeter (ft):	53.57

Morgan Run at Louisville, Maryland

Upstream view of classification cross-section

Left bank of classification cross-section

MORGAN RUN
at Louisville, MD
U.S.G.S. Gage:1586610

Gage

FLOW

London
Bridge
Road

S

Electric Power
Line ROW

Rosgen Classification
Cross-Section

FLOW

Entrance of
Tributary

LEGEND

Top of Bank :	– – – – –
Bankfull :	———
Edge of Water :	– – – – –
Thalweg :	–·–·–·–
Earth :	⊞⊞⊞⊞
Sand/Gravel :	∴∴∴∴
Bed Rock :	⧄⧄⧄⧄
Boulders :	◯◯
Fallen Trees :	🌲
Limit of Study Reach:	▼———▼

Scale (ft):

| 0 | 50 | 100 | 200 |

Survey Dates: 9/24/98 & 9/25/98
Study Reach Length: 1307'
Study Reach 310' U/S of U.S.G.S. Gage
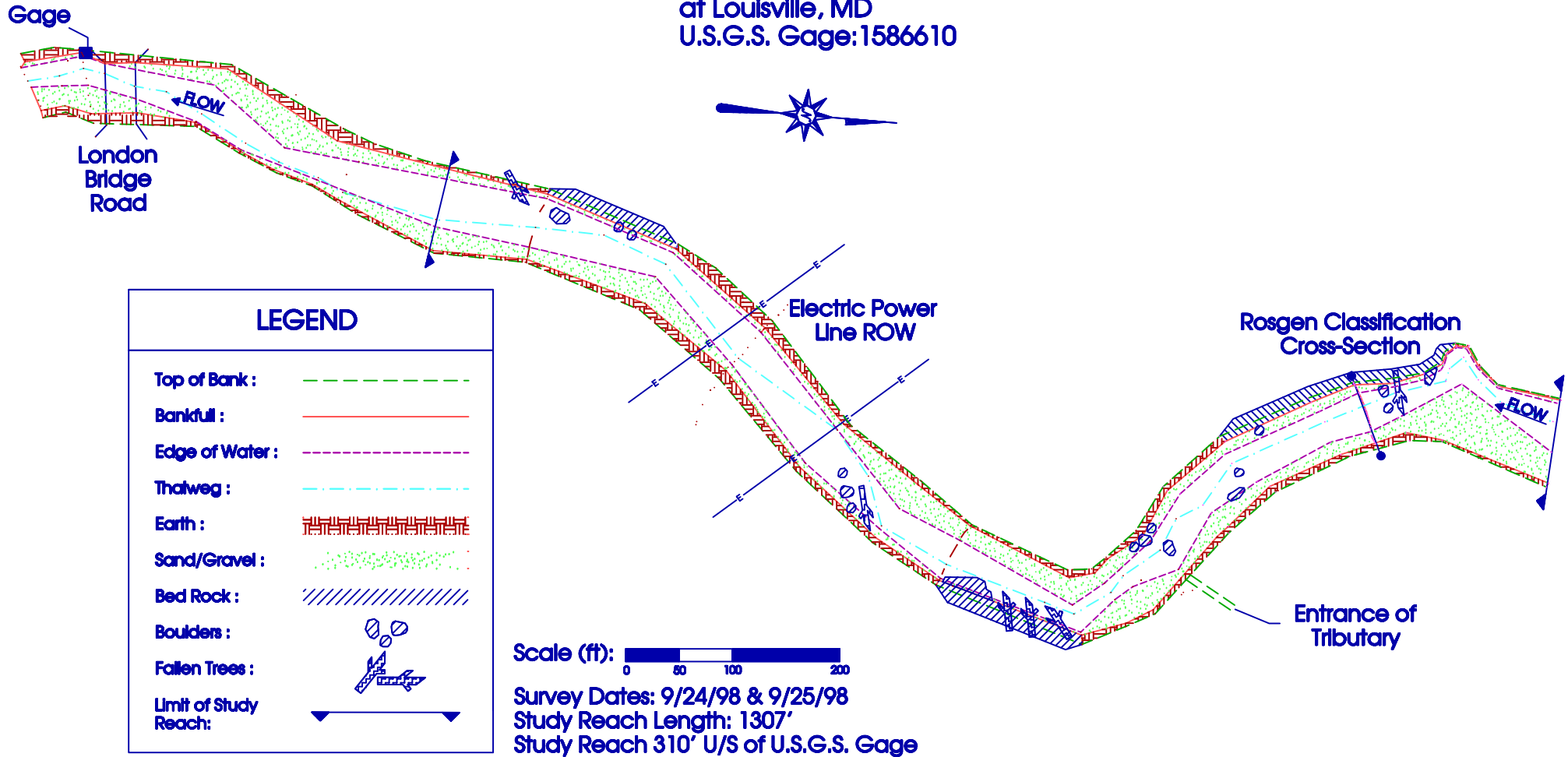
NORTHEAST CREEK AT LESLIE, MD
USGS STATION NUMBER: 1496000

Latitude:	39° 37' 38"	Gage Period of Record:	1948 - 1984
Longitude:	75° 56' 40"	Mean Annual Discharge (cfs):	35.70
ADC Map Coordinates:	Cecil / 1989	Rosgen Stream Type:	C2/1
	Map 11 / E5	Survey Date:	Sept. 1997
Drainage Area (sq. mi.):	24.30		Oct. 1998
Stream Order / Magnitude:	3 / 30		
Percent Imperviousness:	2.85		

Land Use (%):   Residential: 5.47   Agricultural: 72.22   Forest: 18.78   Commercial: 1.79

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 535.70 $Q_{1.5}$: 1200.00 $Q_{2.0}$: 1502.80
(Log-Pearson Period: 1949 - 1984)

General Study Reach Description: The study reach and gage reach are the same. The reach has both step/pool and riffle/pool features, a regular bedrock-controlled meander pattern with slightly developed point bar depositional features, and is stabilized vertically by bedrock outcrops. There is little or no large woody debris, but numerous boulders and bedrock outcrops occur throughout the reach. The bank and floodplain vegetation are moderately dense forest, consisting of tulip poplar, beech, oak, ironwood, and red maple, with a moderately dense understory of mountain laurel and rhododendron.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	1336.00	Q_{bkf} / $Q_{2.0}$:	0.89	
Bankfull Return Interval (R.I.):	1.67	$Q_{Top of Bank}$(cfs):	2386.00	R.I.: 5.50
Gage Height (ft):	4.72	$Q_{Active Channel}$ (cfs):	n/a	R.I.: n/a
Q_{bkf} / $Q_{1.5}$:	1.11			

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0120	Flood-prone Width (ft):	181.00
Manning's "n":	0.052	Entrenchment Ratio:	3.12
Mean Bankfull Velocity (ft/sec):	6.76	Width/Depth Ratio:	17.01
u/u*:	6.14	Channel Sinuosity:	1.11
R/D$_{84}$:	1.77	Beltwidth:	430
Froude Number:	0.65	Meander Width Ratio:	7.4

NORTHEAST CREEK AT LESLIE, MD
PARTICLE SIZE DISTRIBUTION
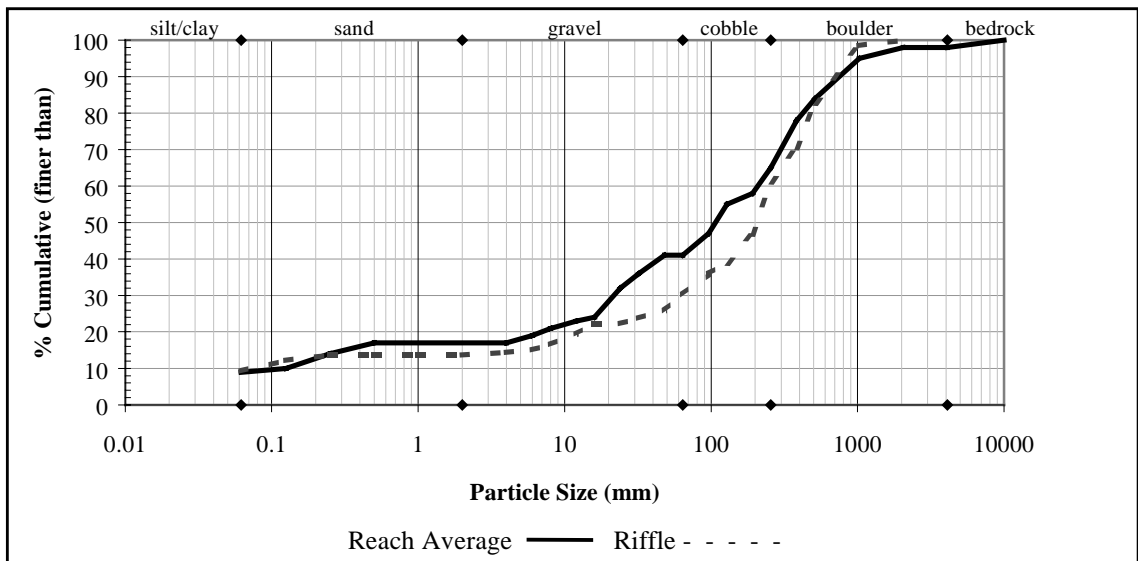
Particle Size (mm)		
Finer Than	Reach	Riffle
D₁₆	0.40	7.17
D₃₅	29.78	89.65
D₅₀	106.94	204.84
D₈₄	512.00	541.19
D₉₅	1024.00	876.13

The reach pebble count distribution is skewed. The reach pebble count D_{50} is cobble. The largest number of observations is in the boulder size class. The riffle pebble count D_{50} is cobble.

STUDY REACH CROSS SECTION
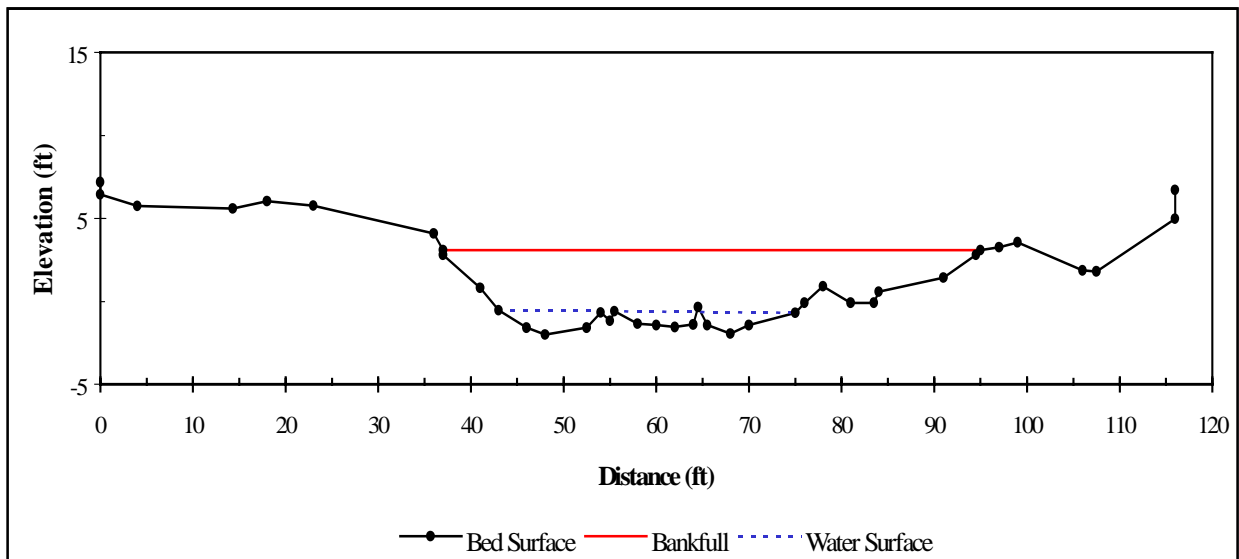
Bankfull Width (ft):	58.00	Mean Bankfull Depth (ft):	3.41
Bankfull Cross-sectional Area (ft^2):	197.62	Maximum Bankfull Depth (ft):	5.09
Hydraulic Radius (ft):	3.15	Wetted Perimeter (ft):	62.75

Northeast Creek at Leslie, Maryland

Upstream view of classification cross-section

Left bank of classification cross-section

NORTHEAST CREEK
at Leslie, MD
U.S.G.S. Gage: 01496000
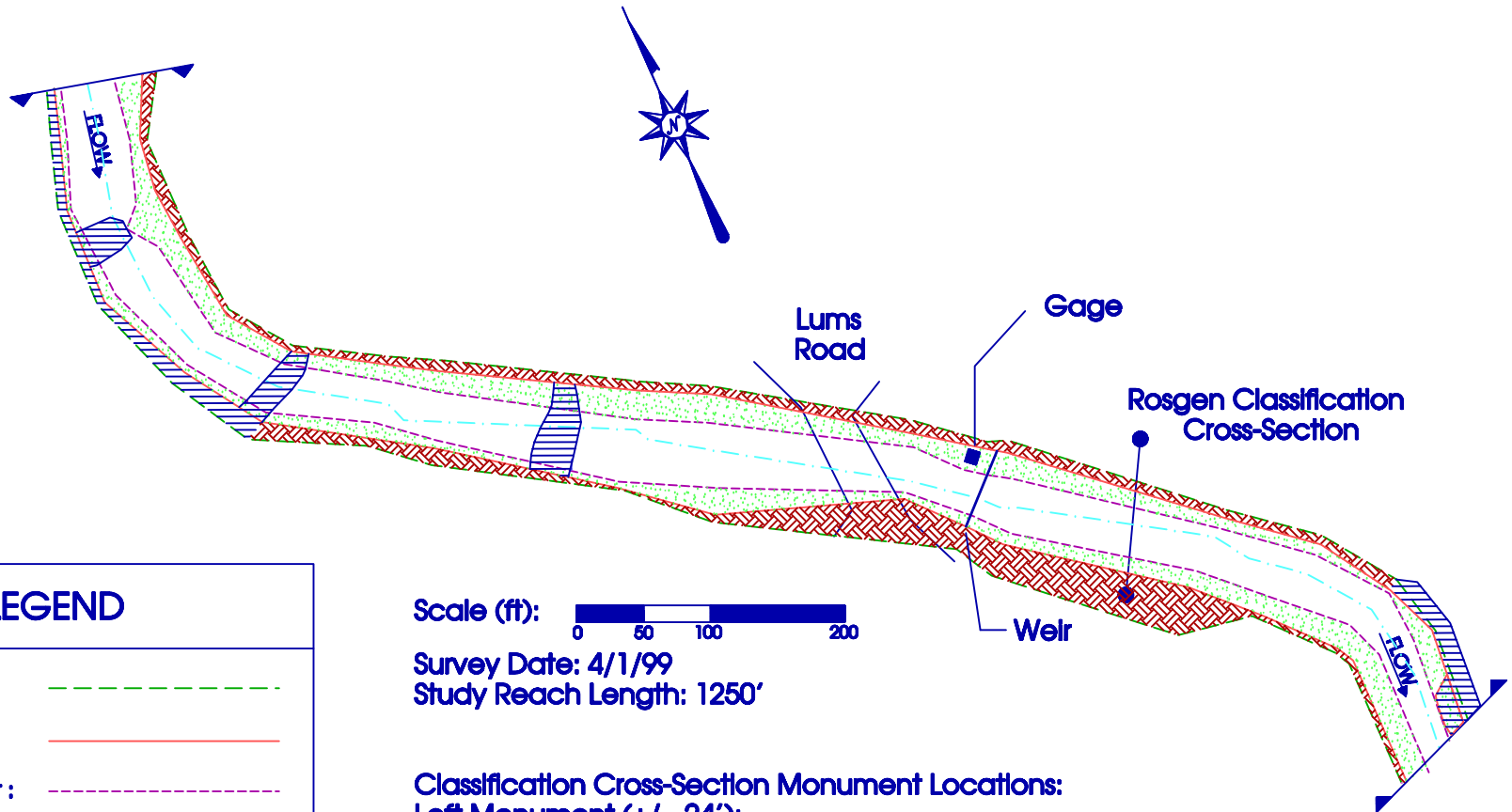
Lums
Road

Gage

Rosgen Classification
Cross-Section

Weir

FLOW

LEGEND

Top of Bank :	– – – – –
Bankfull :	————
Edge of Water :	- - - - -
Thalweg :	—·—·—
Earth :	(hatch pattern)
Sand/Gravel :	(stipple pattern)
Bed Rock :	(diagonal pattern)
Limit of Study Reach:	▼———▼

Scale (ft):

0   50   100   200

Survey Date: 4/1/99
Study Reach Length: 1250'

Classification Cross-Section Monument Locations:
Left Monument (+/- 24'):
39° 37' 38.28" N
75° 56' 37.71" W
Elevation: 325'

Right Monument (+/- 41'):
39° 37' 36.95" N
75° 56' 38.27" W
Elevation: 322'

NORTHWEST BRANCH ANACOSTIA RIVER NEAR COLESVILLE, MD
USGS STATION NUMBER: 1650500

Latitude:	39° 03' 55"	Gage Period of Record:	1924 - 1983
Longitude:	77° 01' 48"		1997 - Present
ADC Map Coordinates:	Montgomery / 1998	Mean Annual Discharge (cfs):	22.50
	Map 31/A9-10	Rosgen Stream Type:	E5/1
Drainage Area (sq. mi.):	21.10	Survey Date:	Oct. 1998
Stream Order / Magnitude:	4 / 47		Dec. 1998
Percent Imperviousness:	16.53		

Land Use (%): Residential: 38.62   Agricultural: 24.35   Forest: 28.80   Commercial: 4.75

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 447.60 $Q_{1.5}$: 960.00 $Q_{2.0}$: 1227.00
(Log-Pearson Period: 1924 - 1983)

General Study Reach Description: The study reach and gage reach are the same. The study reach has run/pool features, a bedrock and boulder revetment controlled meander pattern with minor depositional features, some lateral scour, and is stabilized vertically by bedrock outcrops in the bed. There is no large woody debris in the reach. The bank vegetation is moderately dense forest of box elder, silver maple and sycamore. On the left, the floodplain is old-field with recently planted trees, while the right floodplain is covered by moderately dense forest with a moderately dense understory of sapling trees and spicebush. Immediately upstream of the reach, the stream passes through a 3-cell box culvert, and an abandoned bridge crosses the channel at the downstream end of the reach. The reach appears to have been straightened at some time in the past, and the reach immediately downstream was channelized in the 1930s, according to the USGS gage record.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	907.00	Q_{bkf} / $Q_{2.0}$:	0.74		
Bankfull Return Interval (R.I.):	1.43	$Q_{Top of Bank}$(cfs):	1081.00	R.I.: 1.60	
Gage Height (ft):	6.47	$Q_{Active Channel}$ (cfs):	n/a	R.I.: n/a	
Q_{bkf} / $Q_{1.5}$:	0.94				

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0017	Flood-prone Width (ft):	601.00
Manning's "n":	0.036	Entrenchment Ratio:	14.71
Mean Bankfull Velocity (ft/sec):	4.52	Width/Depth Ratio:	8.32
u/u*:	9.42	Channel Sinuosity:	1.06
R/D$_{84}$:	14.31	Beltwidth:	79
Froude Number:	0.36	Meander Width Ratio:	1.9

NORTHWEST BRANCH ANACOSTIA RIVER NEAR COLESVILLE, MD
PARTICLE SIZE DISTRIBUTION
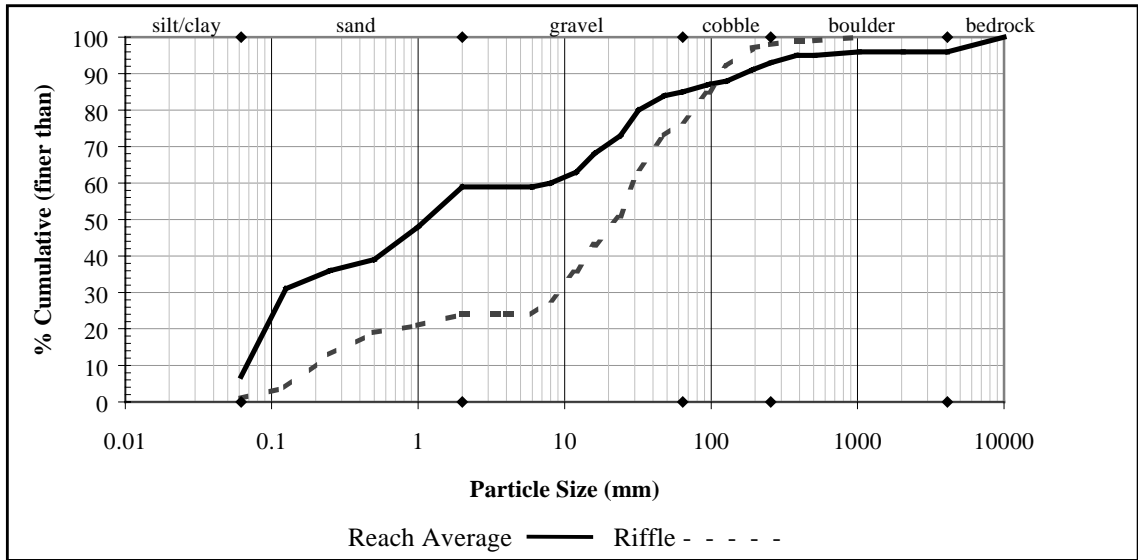
Particle Size (mm)		
Finer Than	Reach	Riffle
D$_{16}$	0.08	0.35
D$_{35}$	0.22	11.41
D$_{50}$	1.13	22.81
D$_{84}$	48.00	91.26
D$_{95}$	512.00	163.25

STUDY REACH CROSS SECTION
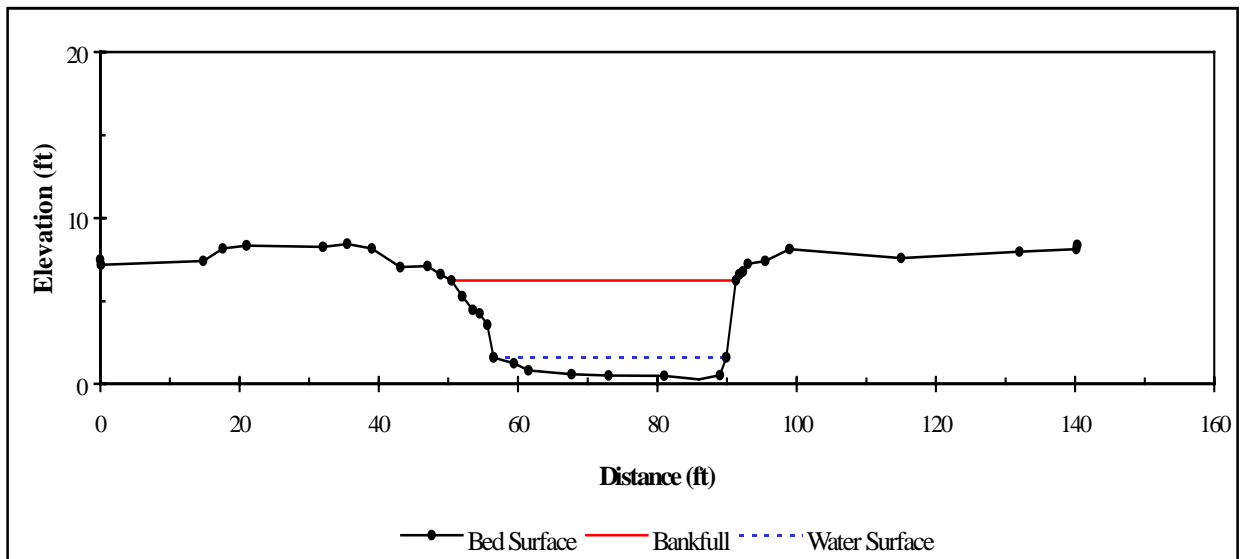
Bankfull Width (ft):	40.85	Mean Bankfull Depth (ft):	4.91
Bankfull Cross-sectional Area (ft^2):	200.68	Maximum Bankfull Depth (ft):	5.97
Hydraulic Radius (ft):	4.28	Wetted Perimeter (ft):	46.84

Northwest Branch of the Anacostia River near Colesville, Maryland

Downstream view of classification cross-section

Right bank of classification cross-section

NORTHWEST BRANCH ANACOSTIA
near Colesville, MD
U.S.G.S Gage:1650500
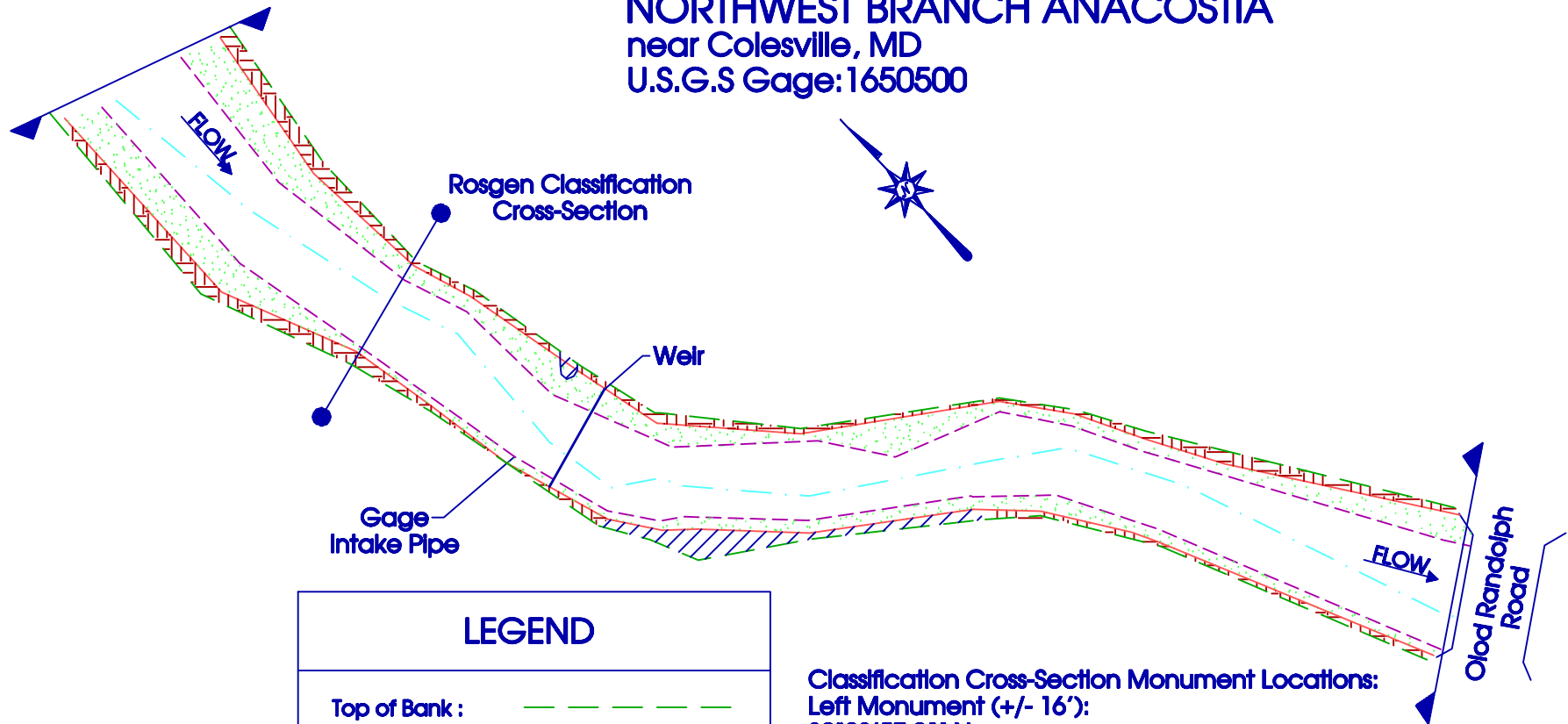
FLOW

Rosgen Classification
Cross-Section

Weir

Gage
Intake Pipe

FLOW

Olod Randolph
Road

LEGEND

Top of Bank :	– – – – –
Bankfull :	————
Edge of Water :	– – – – –
Thalweg :	–·–·–·–
Earth :	
Sand/Gravel :	
Bed Rock :	/////////
Limit of Study Reach:	▼——————▼

Classification Cross-Section Monument Locations:
Left Monument (+/- 16'):
39°03'57.01" N
77°01'44.81" W
Elevation: 257'

Right Monument (+/- 20'):
39°03'56.69" N
77°01'46.63" W
Elevation: 302'

Scale (ft):

0	50	100	200

Survey Date:12/22/98
Study Reach Length: 646'

PATUXENT RIVER NEAR UNITY, MD
USGS STATION NUMBER: 1591000

Latitude:	39° 14' 18"	Gage Period of Record:	1944 - Present
Longitude:	77° 03' 23"	Mean Annual Discharge (cfs):	39.40
ADC Map Coordinates:	Montgomery / 1998	Rosgen Stream Type:	C4
	Map 12 / G4	Survey Date:	Oct. 1997
Drainage Area (sq. mi.):	34.80		Jan. 1999
Stream Order / Magnitude:	4 / 64		
Percent Imperviousness:	2.14		

Land Use (%):   Residential: 5.96   Agricultural: 56.84   Forest: 36.15   Commercial: 0.79

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 284.80 $Q_{1.5}$: 1050.00 $Q_{2.0}$: 1495.10
(Log-Pearson Period: 1945 - 1995)

General Study Reach Description: The downstream end of the study reach is 2,500 feet upstream of the gage because of a long intervening reach of divided channel, and potential reservoir backwater effects below the gage. The reach has pool/riffle features, a regular meander pattern with point, side, and mid-channel bars (the latter associated with debris blockages), some lateral scour, and appears vertically stable. There are several pieces of large woody debris, some span or greatly block the channel, and numerous boulders throughout the reach. The bank vegetation is mature red maple and sycamore, while the floodplain vegetation is a mix of pasture and forest with a sparse to moderately dense understory.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	1045.00	Q_{bkf} / $Q_{2.0}$:	0.70	
Bankfull Return Interval (R.I.):	1.50	$Q_{Top of Bank}$(cfs):	1777.00	R.I.: 2.40
Gage Height (ft):	6.10	$Q_{Active Channel}$ (cfs):	n/a	R.I.: n/a
Q_{bkf} / $Q_{1.5}$:	1.00			

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0021	Flood-prone Width (ft):	428.00
Manning's "n":	0.030	Entrenchment Ratio:	8.23
Mean Bankfull Velocity (ft/sec):	5.17	Width/Depth Ratio:	13.37
u/u*:	10.77	Channel Sinuosity:	1.26
R/D$_{84}$:	26.88	Beltwidth:	310
Froude Number:	0.46	Meander Width Ratio:	6.0

PATUXENT RIVER NEAR UNITY, MD
PARTICLE SIZE DISTRIBUTION
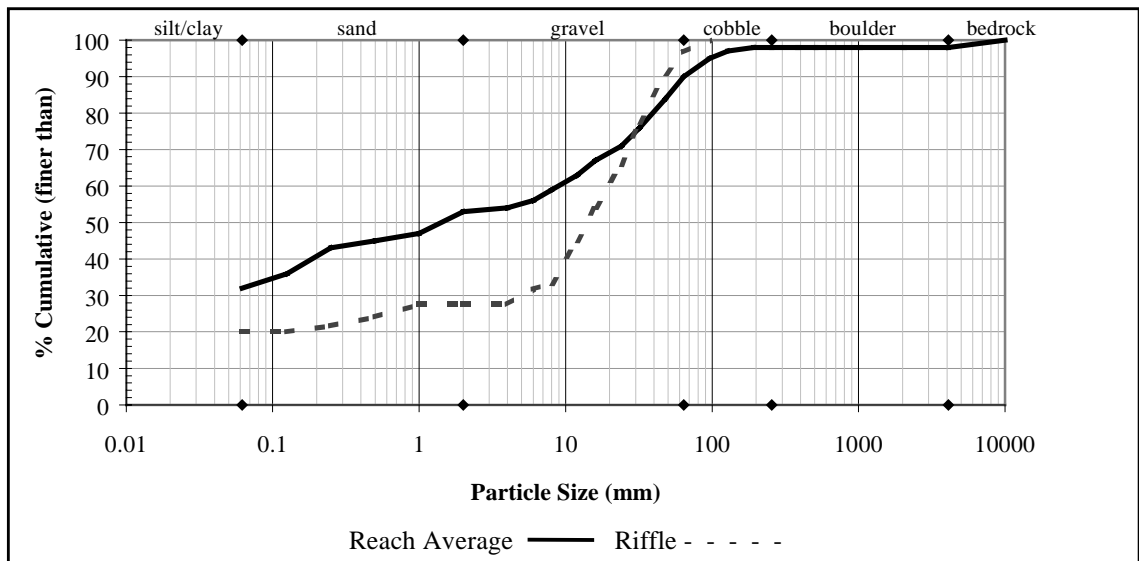
Particle Size (mm)		
Finer Than	Reach	Riffle
D 16	n/a	n/a
D 35	0.10	8.48
D 50	1.41	14.04
D 84	48.00	38.99
D 95	96.00	58.95

The reach pebble count distribution is bi-modal (silt/clay and gravel). The largest number of oberservations is in the gravel size class. The riffle pebble count D_{50} is gravel.

STUDY REACH CROSS SECTION
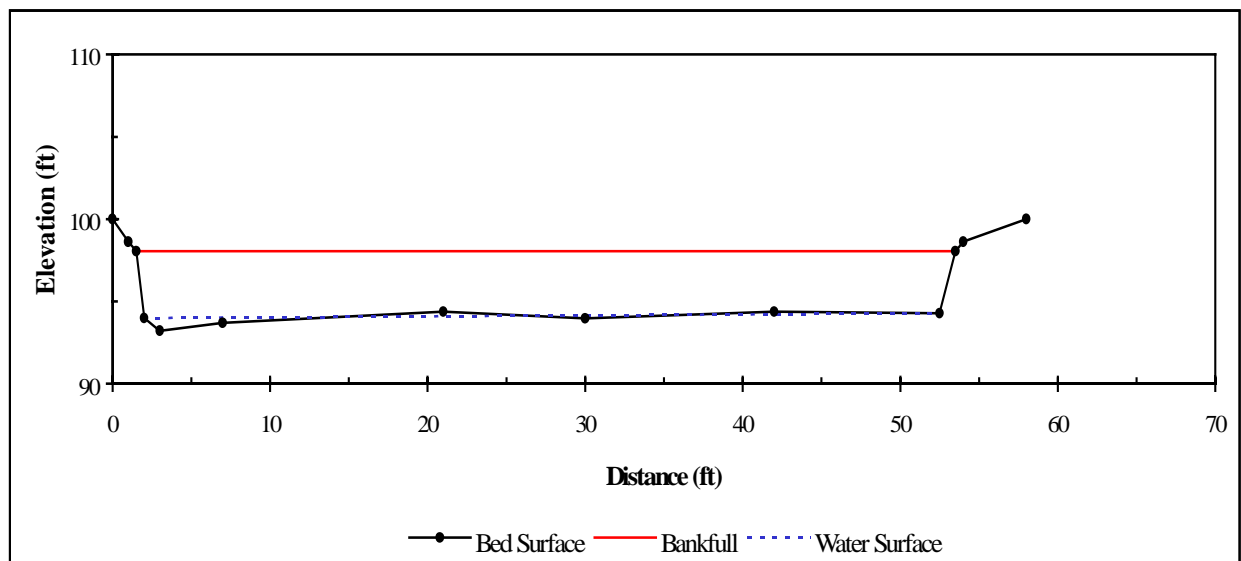
Bankfull Width (ft):	52.00	Mean Bankfull Depth (ft):	3.89
Bankfull Cross-sectional Area (ft^2):	202.20	Maximum Bankfull Depth (ft):	4.82
Hydraulic Radius (ft):	3.44	Wetted Perimeter (ft):	58.80

Patuxent River near Unity, Maryland

Upstream view of classification cross-section

Left bank of classification cross-section

PATUXENT RIVER
near Unity, MD
U.S.G.S. Gage:1591000
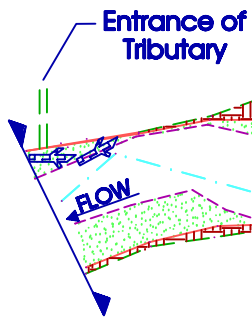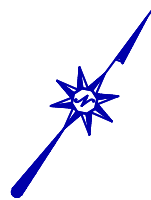
FLOW

FLOW

Entrance of Tributary

Rosgen Classification Cross-Section

FLOW

LEGEND

Top of Bank :	– – – – –
Bankfull :	———
Edge of Water :	– – – – –
Thalweg :	– · – · –
Earth :	▦▦▦
Sand/Gravel :	░░░
Boulders :	⬭⬭
Fallen Trees :	⋇⋇
Limit of Study Reach:	◄———►

Scale (ft):

0   50   100   200

Survey Dates:1/26/99 & 1/27/99
Study Reach Length; 1243'
Study Reach 2498' U/S of U.S.G.S. Gage

PINEY CREEK NEAR TANEYTOWN, MD
USGS STATION NUMBER: 1639140

Latitude:	39° 39' 38"	Gage Period of Record:	1990 - Present
Longitude:	77° 13' 16"	Mean Annual Discharge (cfs):	40.40
ADC Map Coordinates:	Carroll / 1990	Rosgen Stream Type:	C4/1
	Map 9 / C2	Survey Date:	Oct. 1998
Drainage Area (sq. mi.):	31.30		Dec. 1998
Stream Order / Magnitude:	4 / 44		
Percent Imperviousness:	3.96		

Land Use (%):   Residential: 8.37   Agricultural: 79.22   Forest: 10.64   Commercial: 1.74

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: n/a $Q_{1.5}$: 1525.00 $Q_{2.0}$: 1930.00
(Log-Pearson Period: 1990 - 1998)

General Study Reach Description: The study reach and the gage reach are the same. The reach has pool/riffle features, a bedrock-controlled meander pattern with point and side bar depositional features, some lateral scour, and is stabilized vertically by bedrock outcrops. There is no large woody debris in the reach. The bank vegetation is mature green ash, red maple and sycamore. On the left and on the downstream right, the floodplain vegetation is mature forest with moderately dense understory of shrubs and sapling trees, while the floodplain vegetation on the upper right is pasture. Cattle have unrestricted access to the channel over the entire reach. Upstream of the study reach the channel appears to have been straightened at some time in the past. Roop Road crosses the channel on a bridge at the lower end of the reach.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	1389.00	Q_{bkf} / $Q_{2.0}$:	0.72	
Bankfull Return Interval (R.I.):	1.40	$Q_{Top of Bank}$(cfs):	1949.00	R.I.: 2.00
Gage Height (ft):	5.94	$Q_{Active Channel}$ (cfs):	n/a	R.I.: n/a
Q_{bkf} / $Q_{1.5}$:	0.91			

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0025	Flood-prone Width (ft):	600.00
Manning's "n":	0.032	Entrenchment Ratio:	9.12
Mean Bankfull Velocity (ft/sec):	5.58	Width/Depth Ratio:	17.41
u/u*:	10.33	Channel Sinuosity:	1.47
R/D_{84}:	8.99	Beltwidth:	334
Froude Number:	0.51	Meander Width Ratio:	5.1

PINEY CREEK NEAR TANEYTOWN, MD
PARTICLE SIZE DISTRIBUTION
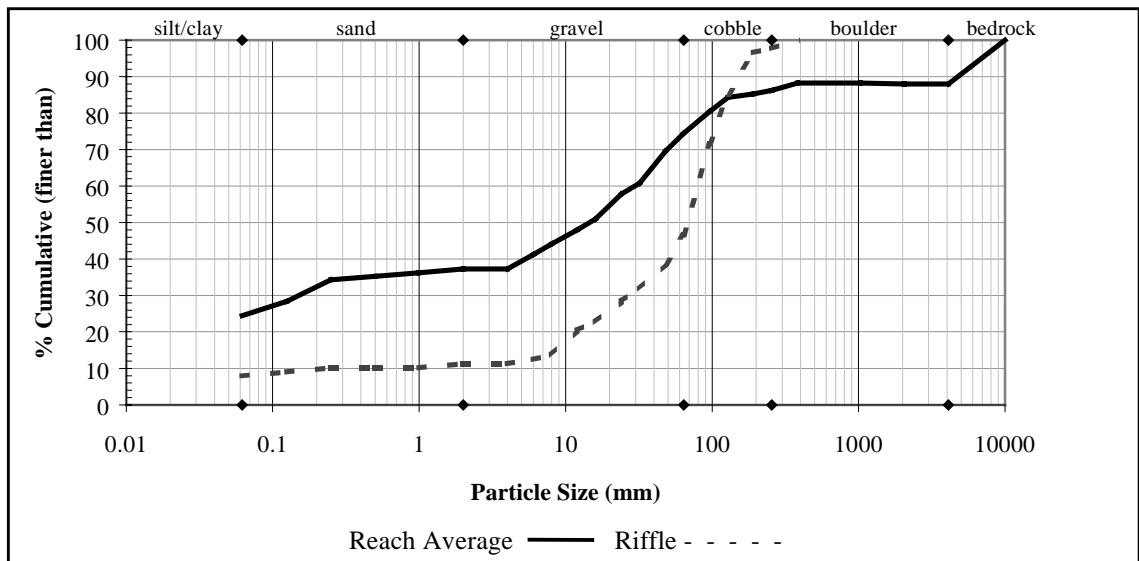
Particle Size (mm)		
Finer Than	Reach	Riffle
D$_{16}$	n/a	9.21
D$_{35}$	0.41	38.67
D$_{50}$	14.54	67.64
D$_{84}$	125.09	124.73
D$_{95}$	Bedrock	181.40

STUDY REACH CROSS SECTION
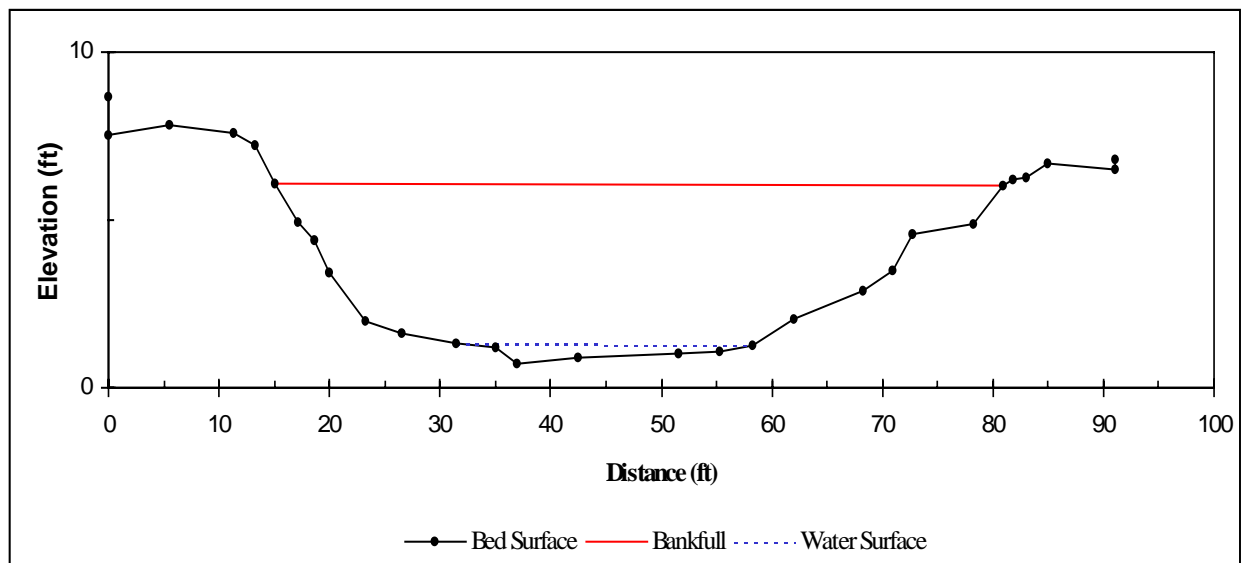
Bankfull Width (ft):	65.80	Mean Bankfull Depth (ft):	3.78
Bankfull Cross-sectional Area (ft^2):	248.90	Maximum Bankfull Depth (ft):	5.36
Hydraulic Radius (ft):	3.68	Wetted Perimeter (ft):	67.68

Piney Creek at Taneytown, Maryland

Downstream view of classification cross-section

Left bank of classification cross-section

Piney Creek at Taneytown

PINEY CREEK
at Taneytown, MD
U.S.G.S. Gage:1639140

Roop Road

Gage

Rosgen Classification Cross-Section

FLOW

FLOW

N
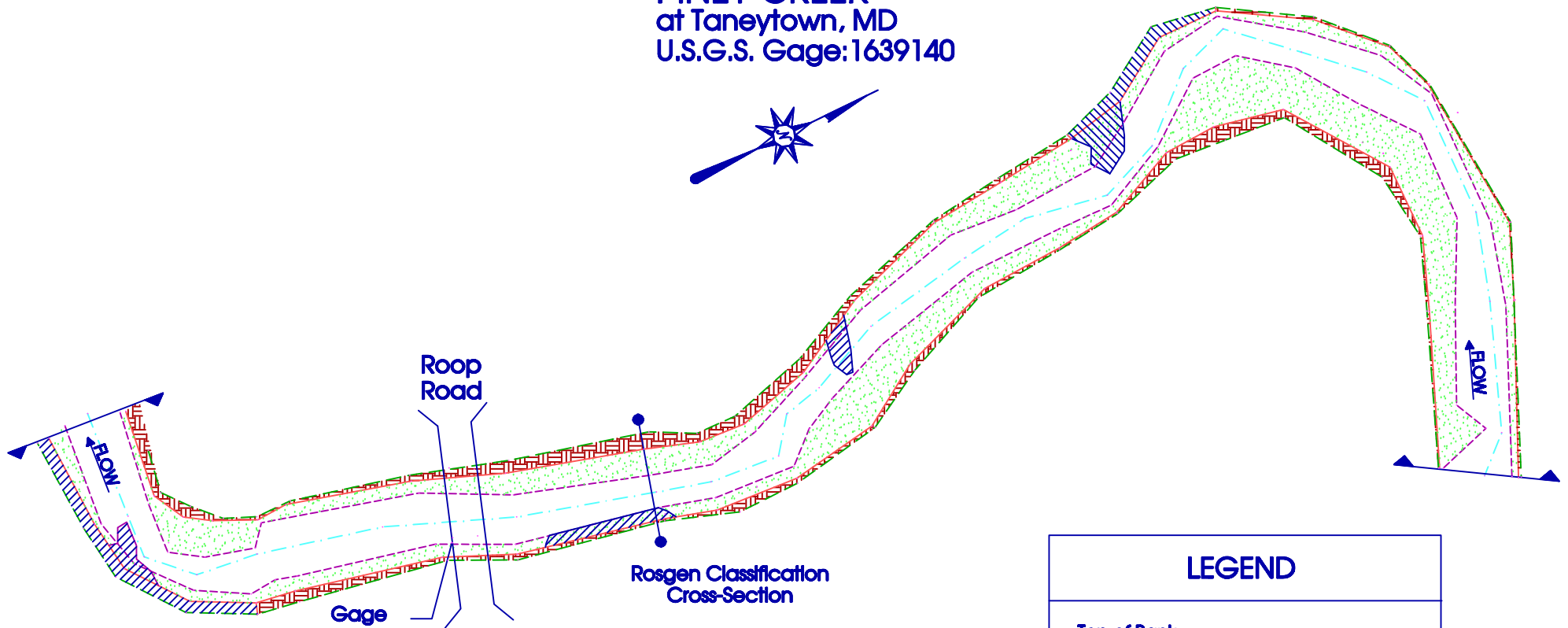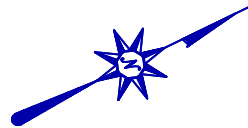
Scale (ft):

0   50   100   200

Survey Dates: 12/29/98 & 12/30/98
Study Reach Length: 1784'

Classification Cross-Section Monument Locations:
Left Monument (+/- 15'):   Right Monument (+/- 12):
39° 39' 40.63" N   39° 39' 40.33" N
77° 13' 13.97" W   77° 13' 15.17" W
Elevation 462'   Elevation 419'

LEGEND

Top of Bank :	– – – – – –
Bankfull :	————
Edge of Water :	– – – – – –
Thalweg :	–·–·–·–
Earth :	(hatched)
Sand/Gravel :	(dotted)
Bed Rock :	////////////
Limit of Study Reach:	▼———▼

SENECA CREEK AT DAWSONVILLE, MD
USGS STATION NUMBER: 1645000

Latitude:	39° 07' 41"	Gage Period of Record:	1930 - Present
Longitude:	77° 20' 13"	Mean Annual Discharge (cfs):	109.00
ADC Map Coordinates:	Montgomery / 1998	Rosgen Stream Type:	C4
	Map 17 / E11	Survey Date:	Nov. 1997
Drainage Area (sq. mi.):	101.00		
Stream Order / Magnitude:	5 / 189		
Percent Imperviousness:	12.04		

Land Use (%):   Residential: 20.35   Agricultural: 42.48   Forest: 28.72   Commercial: 5.03

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 831.20 $Q_{1.5}$: 3050.00 $Q_{2.0}$: 4322.00
(Log-Pearson Period: 1968 - 1998)

General Study Reach Description: The upstream end of the study reach is 103 feet downstream of the gage, the channel forks a few hundred feet upstream of the gage. The study reach has pool/riffle features, a straight meander pattern with point and side bars, some lateral scour, and appears vertically stable. There are several pieces of large woody debris in the reach, but none that extend across or well into the channel. The bank vegetation is forest, consisting of sycamore, river birch and ironwood with a low-density understory, while the floodplain vegetation is mostly pasture/hay field.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	2562.00	Q_{bkf} / $Q_{2.0}$:	0.59		
Bankfull Return Interval (R.I.):	1.33	$Q_{Top of Bank}$(cfs):	n/a	R.I.: n/a	
Gage Height (ft):	7.53	$Q_{Active Channel}$ (cfs):	761.20	R.I.: <1.005	
Q_{bkf} / $Q_{1.5}$:	0.84				

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0014	Flood-prone Width (ft):	803.00
Manning's "n":	0.027	Entrenchment Ratio:	12.02
Mean Bankfull Velocity (ft/sec):	6.38	Width/Depth Ratio:	11.11
u/u^*:	12.76	Channel Sinuosity:	1.05
R/D_{84}:	118.53	Beltwidth:	99
Froude Number:	0.46	Meander Width Ratio:	1.5

SENECA CREEK AT DAWSONVILLE, MD
PARTICLE SIZE DISTRIBUTION
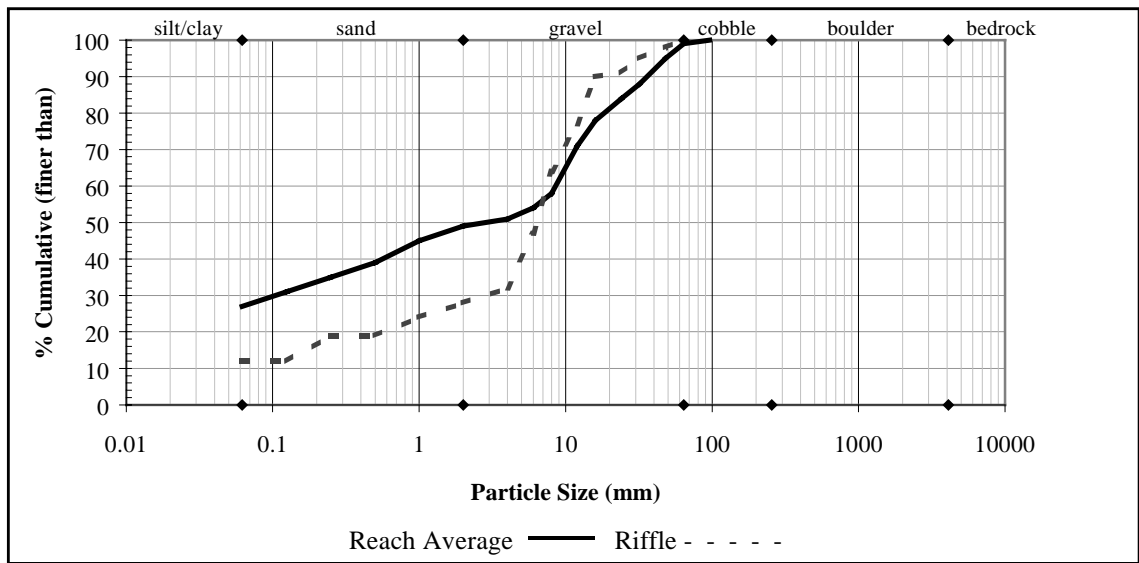
Particle Size (mm)		
Finer Than	Reach	Riffle
D_{16}	n/a	0.19
D_{35}	0.25	4.34
D_{50}	2.83	6.31
D_{84}	24.00	14.01
D_{95}	48.00	32.00

STUDY REACH CROSS SECTION
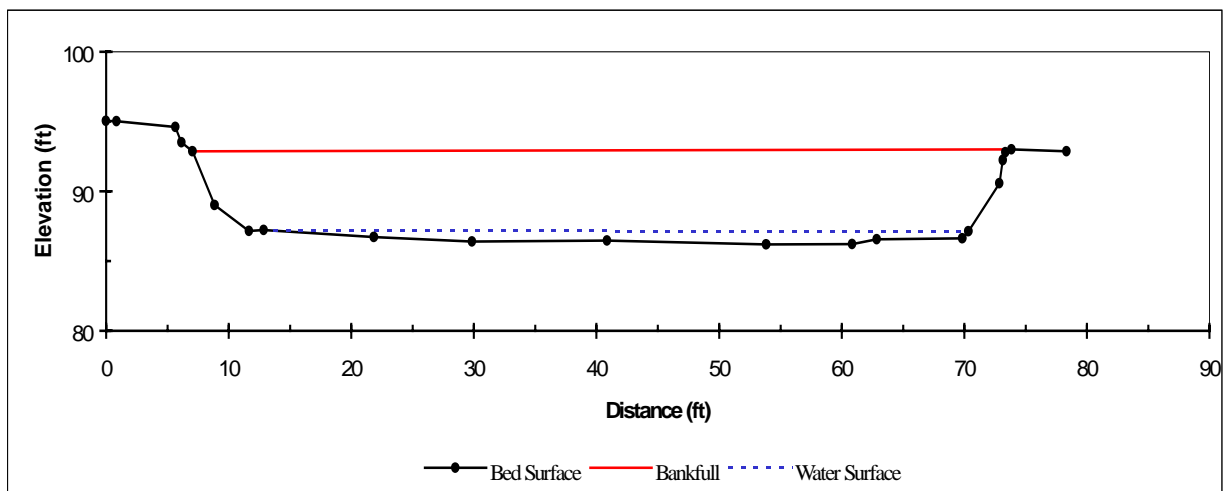
Bankfull Width (ft):	66.80	Mean Bankfull Depth (ft):	6.01
Bankfull Cross-sectional Area (ft^2):	401.37	Maximum Bankfull Depth (ft):	6.72
Hydraulic Radius (ft):	5.45	Wetted Perimeter (ft):	73.67

Seneca Creek at Dawnsonville, Maryland

Upstream view of classification cross-section

Right bank of classification cross-section

SENECA CREEK
at Dawsonville, MD
USGS Gage:1645000
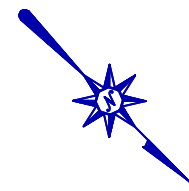
Rosgen Classification
Cross-Section

LEGEND

Top of Bank :	
Bankfull :	
Edge of Water :	
Thalweg :	
Earth :	
Sand/Gravel :	
Fallen Trees :	
Limit of Study Reach:	

Scale (ft):
0   50   100   200

Survey Date: 12/9/98
Study Reach Length: 1214'
Study Reach 103' D/S of U.S.G.S. Gage
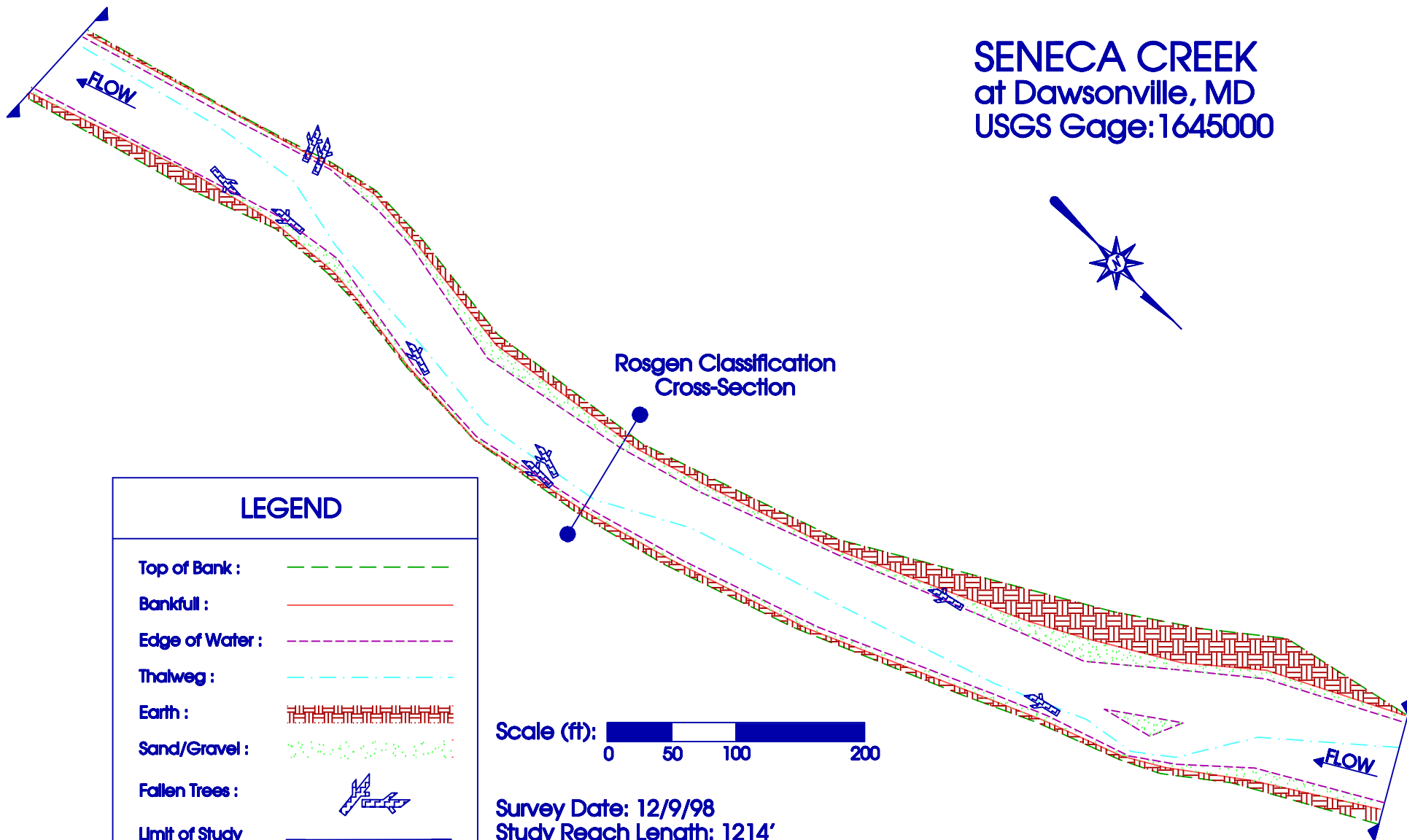
SLADE RUN NEAR GLYNDON, MD
USGS STATION NUMBER: 1583000

Latitude:	39° 29' 40"	Gage Period of Record:	1947 – 1981
Longitude:	76° 47' 45"	Mean Annual Discharge (cfs):	2.40
ADC Map Coordinates:	Baltimore / 1993	Rosgen Stream Type:	E4
	Map 16 / E-F2	Survey Date:	June 1998
Drainage Area (sq. mi.):	2.09		Oct. 1998
Stream Order / Magnitude:	2 / 5		
Percent Imperviousness:	7.87		

Land Use (%):   Residential: 5.66   Agricultural: 44.65   Forest: 42.13   Commercial: 7.55

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 46.30 $Q_{1.5}$: 125.00 $Q_{2.0}$: 154.40
(Log-Pearson Period: 1948 - 1981)

General Study Reach Description: The study reach and gage reach are the same. The reach has pool/riffle features, a regular meander pattern with no bar depositional features, little lateral scour, and appears vertically stable. There is no large woody debris in the reach. The bank vegetation is willow and alder shrub with scattered trees, while the floodplain vegetation is pasture. Livestock have unrestricted access to the stream channel.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	114.80	Q_{bkf} / $Q_{2.0}$:	0.74		
Bankfull Return Interval (R.I.):	1.40	$Q_{Top of Bank}$(cfs):	240.80	R.I.:	4.60
Gage Height (ft):	3.54	$Q_{Active Channel}$ (cfs):	n/a	R.I.:	n/a
Q_{bkf} / $Q_{1.5}$:	0.92				

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0120	Flood-prone Width (ft):	446.00
Manning's "n":	0.043	Entrenchment Ratio:	33.76
Mean Bankfull Velocity (ft/sec):	5.99	Width/Depth Ratio:	9.11
u/u*:	6.30	Channel Sinuosity:	1.07
R/D_{84}:	2.71	Beltwidth:	25
Froude Number:	0.88	Meander Width Ratio:	1.9

SLADE RUN NEAR GLYNDON, MD
PARTICLE SIZE DISTRIBUTION
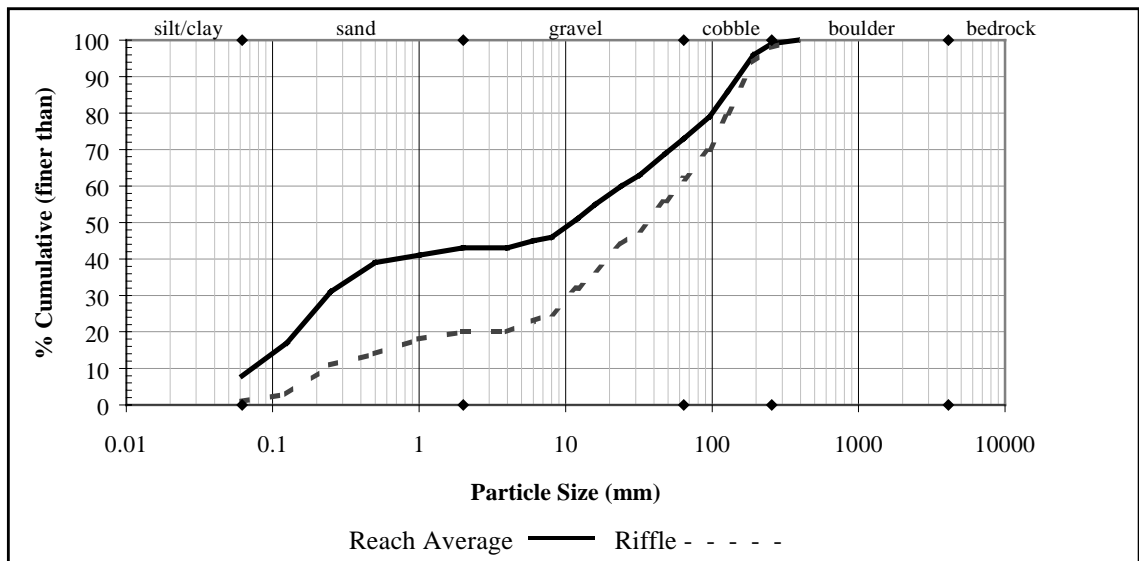
Particle Size (mm)		
Finer Than	Reach	Riffle
D 16	0.11	0.71
D 35	0.35	14.26
D 50	10.69	35.41
D 84	119.46	143.72
D 95	186.52	206.32

STUDY REACH CROSS SECTION
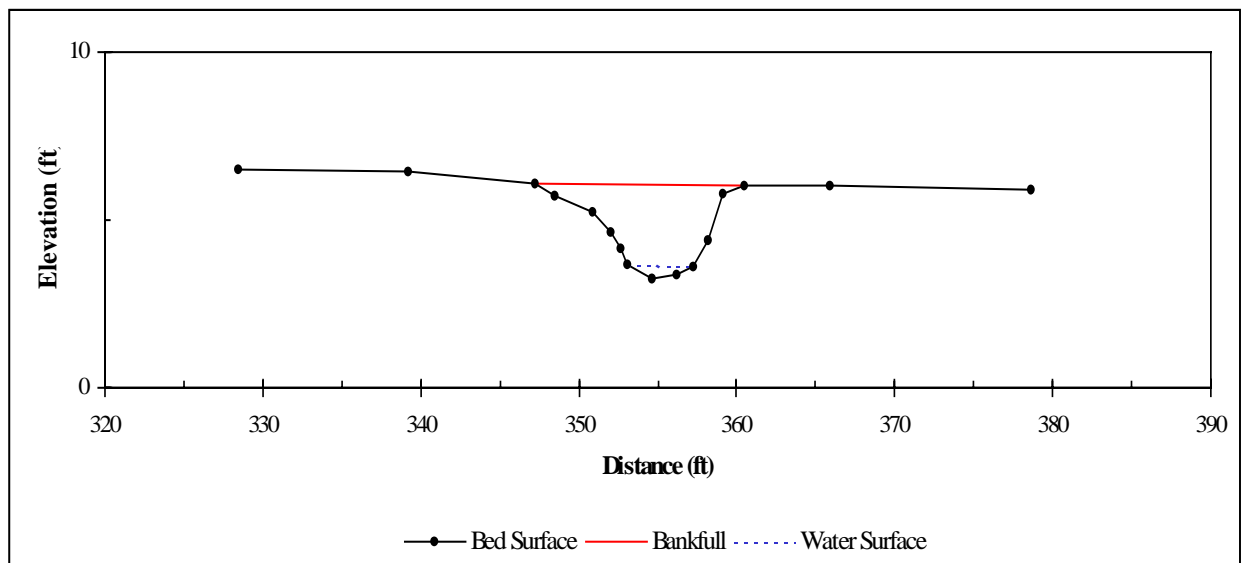
Bankfull Width (ft):	13.21	Mean Bankfull Depth (ft):	1.45
Bankfull Cross-sectional Area (ft^2):	19.15	Maximum Bankfull Depth (ft):	2.83
Hydraulic Radius (ft):	1.28	Wetted Perimeter (ft):	14.98

Slade Run near Glyndon, Maryland

Downstream view of classification cross-section

Left bank of classification cross-section

SLADE RUN
near Glyndon, MD
U.S.G.S. Gage:1583000

Gage

Longnecker
Road

FLOW

Rosgen Classification
Cross-Section

Gage Weir

FLOW
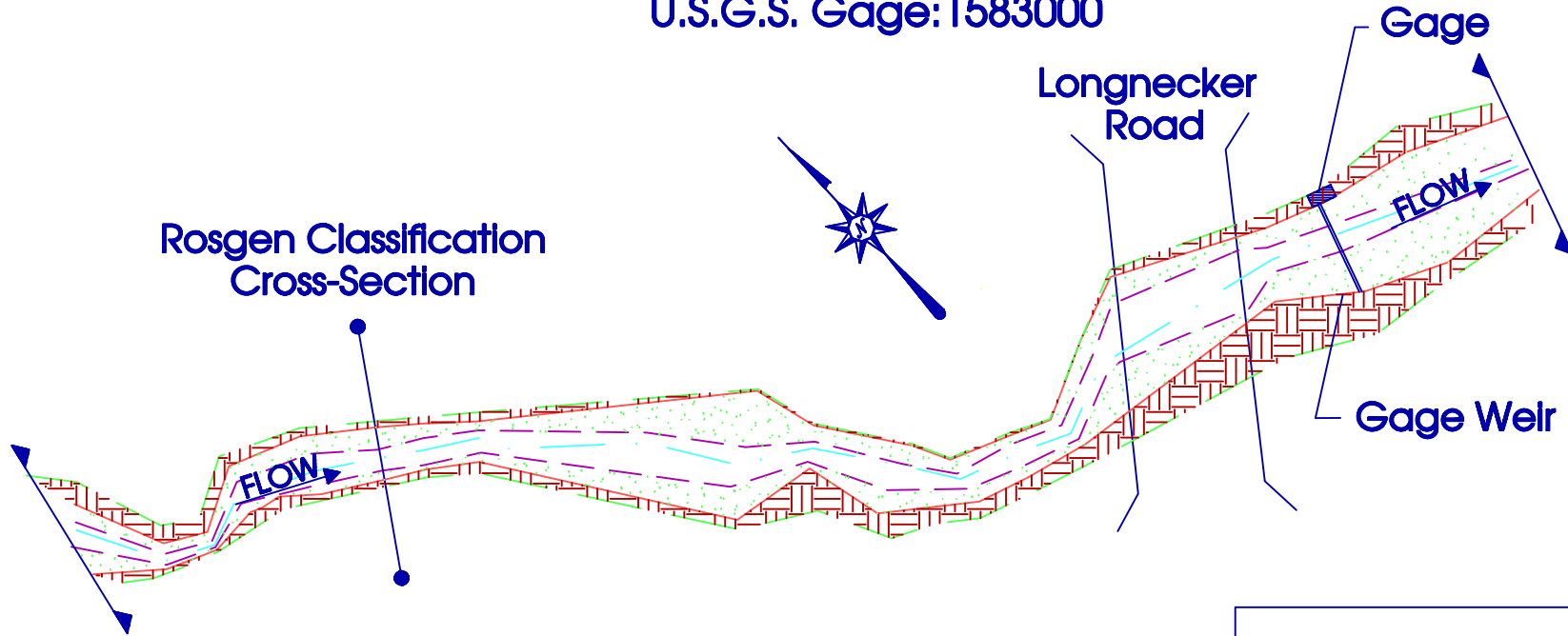
Scale (ft):

0   25   50   100

Survey Date: 10/7/98
Study Reach Length: 314'

Classificaiton Cross-Section Monument Locations:

Left Monument (+/-12')	Right Monument (+/-12')
39* 29' 7.36" N	39* 29' 7.27" N
76* 47' 7.40" W	76* 47' 7.42" W
Elevation: 458'	Elevation: 460'

LEGEND

Top of Bank :	— — —
Bankfull :	————
Edge of Water :	– – –
Thalweg :	–·–·–
Earth :	(hatched)
Sand/Gravel :	(stippled)
Limit of Study Reach:	◄———►

WESTERN RUN AT WESTERN RUN, MD
USGS STATION NUMBER: 1583500

Latitude:	39° 30' 38"	Gage Period of Record:	1944 - Present
Longitude:	76° 40' 37"	Mean Annual Discharge (cfs):	69.70
ADC Map Coordinates:	Baltimore / 1993	Rosgen Stream Type:	C4/1
	Map 12 / C12	Survey Date:	Oct. 1997
Drainage Area (sq. mi.):	59.80		
Stream Order / Magnitude:	5 / 135		
Percent Imperviousness:	3.40		

Land Use (%):   Residential: 8.79   Agricultural: 57.71   Forest: 31.88   Commercial: 1.39

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 528.00 $Q_{1.5}$: 1550.00 $Q_{2.0}$: 2134.70
(Log-Pearson Period: 1945 - 1995)

General Study Reach Description: The upstream end of the study reach is 430 feet downstream of the gage due to the Western Run Road bridge channel constriction. The reach has riffle/pool features, a bedrock-controlled meander pattern with mid-channel, point, and side bar depositional features, and some lateral scour. There are numerous pieces of large woody debris, some of which extend well into the channel, and numerous boulders throughout the reach. The bank vegetation is comprised of sycamore, walnut and ironwood trees with a moderately dense understory, while the floodplain vegetation is a mix of pasture and moderately dense forest with a moderately dense understory of sapling trees and shrubs.

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	1531.00	Q_{bkf} / $Q_{2.0}$:	0.72	
Bankfull Return Interval (R.I.):	1.47	$Q_{Top of Bank}$(cfs):	2225.00	R.I.: 2.12
Gage Height (ft):	5.26	$Q_{Active Channel}$ (cfs):	666.40	R.I.: 1.03
Q_{bkf} / $Q_{1.5}$:	0.99			

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0024	Flood-prone Width (ft):	1591.00
Manning's "n":	0.038	Entrenchment Ratio:	21.10
Mean Bankfull Velocity (ft/sec):	4.88	Width/Depth Ratio:	18.13
$u/u*$:	8.71	Channel Sinuosity:	1.47
R/D_{84}:	28.23	Beltwidth:	600
Froude Number:	0.42	Meander Width Ratio:	8.0

WESTERN RUN AT WESTERN RUN, MD
PARTICLE SIZE DISTRIBUTION
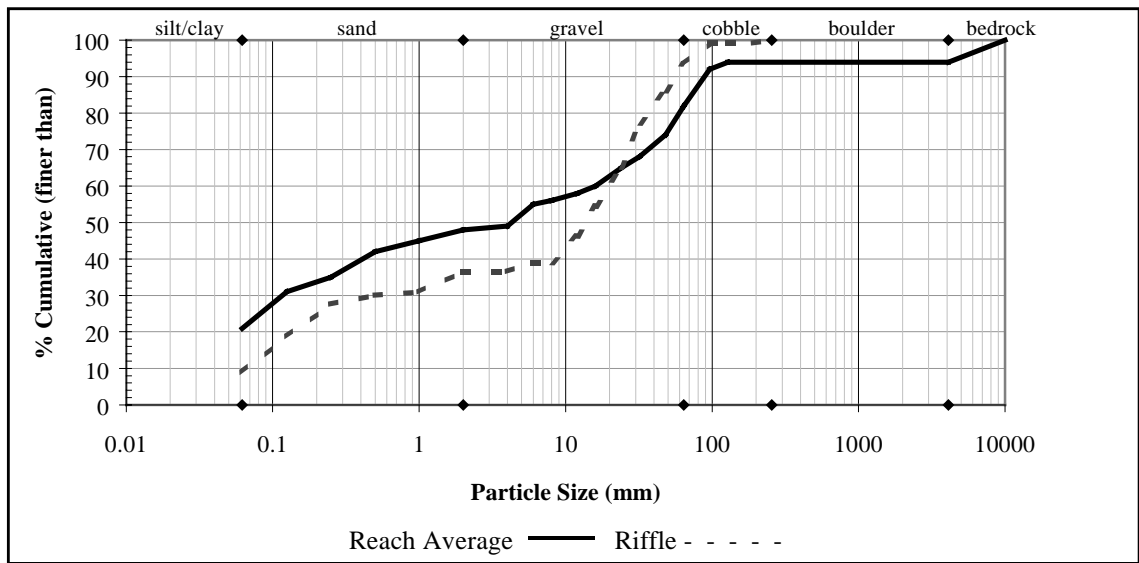
Particle Size (mm)		
Finer Than	Reach	Riffle
D_{16}	n/a	0.10
D_{35}	0.25	1.65
D_{50}	4.28	13.66
D_{84}	69.41	43.48
D_{95}	Bedrock	71.24

STUDY REACH CROSS SECTION
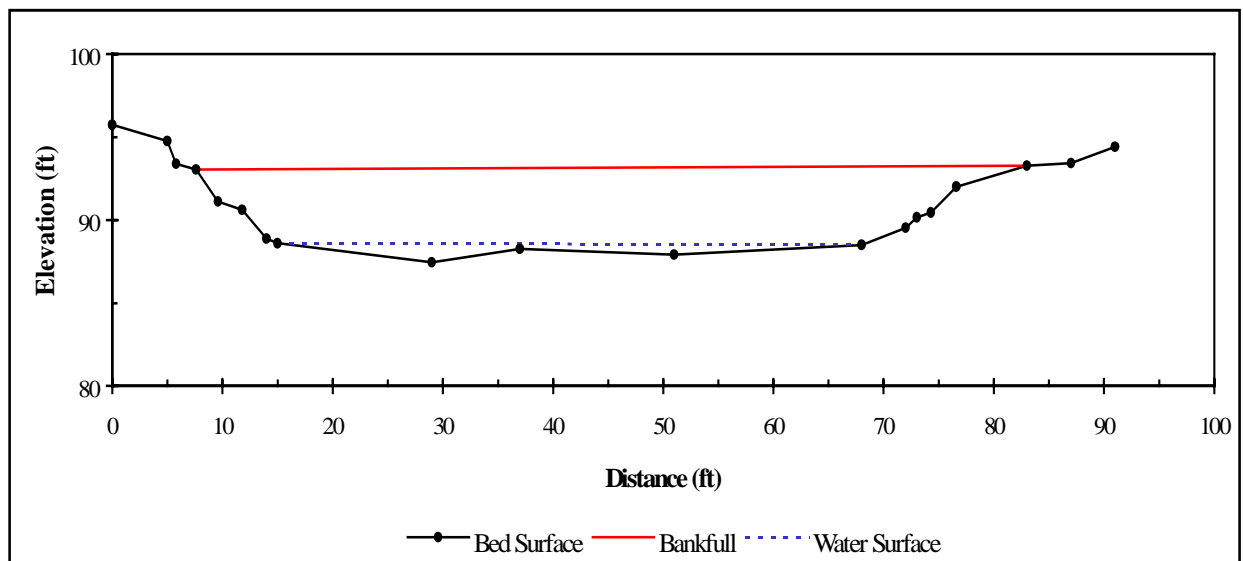
Bankfull Width (ft):	75.40	Mean Bankfull Depth (ft):	4.16
Bankfull Cross-sectional Area (ft^2):	313.81	Maximum Bankfull Depth (ft):	5.63
Hydraulic Radius (ft):	4.03	Wetted Perimeter (ft):	77.93

Western Run at Western Run, Maryland

Downstream view of classification cross-section

Right bank of classification cross-section

WESTERN RUN
at Western Run, MD
U.S.G.S. Gage:1583500

N

FLOW

Rosgen Classification
Cross-Section

FLOW

FLOW

LEGEND

Top of Bank :	– – – – – –
Bankfull :	————
Edge of Water :	– – – – – –
Thalweg :	–·–·–·–
Earth :	⊔⊓⊔⊓⊔⊓
Sand/Gravel :	░░░░░░
Bed Rock :	/////////
Boulders :	⬭⬮
Fallen Trees :	🌲🌲
Limit of Study Reach:	◄————►

Scale:

0	50	100	200

Survey Date: 12/14/98
Reach Length: 1487'
Study Reach 430' D/S of U.S.G.S. Gage
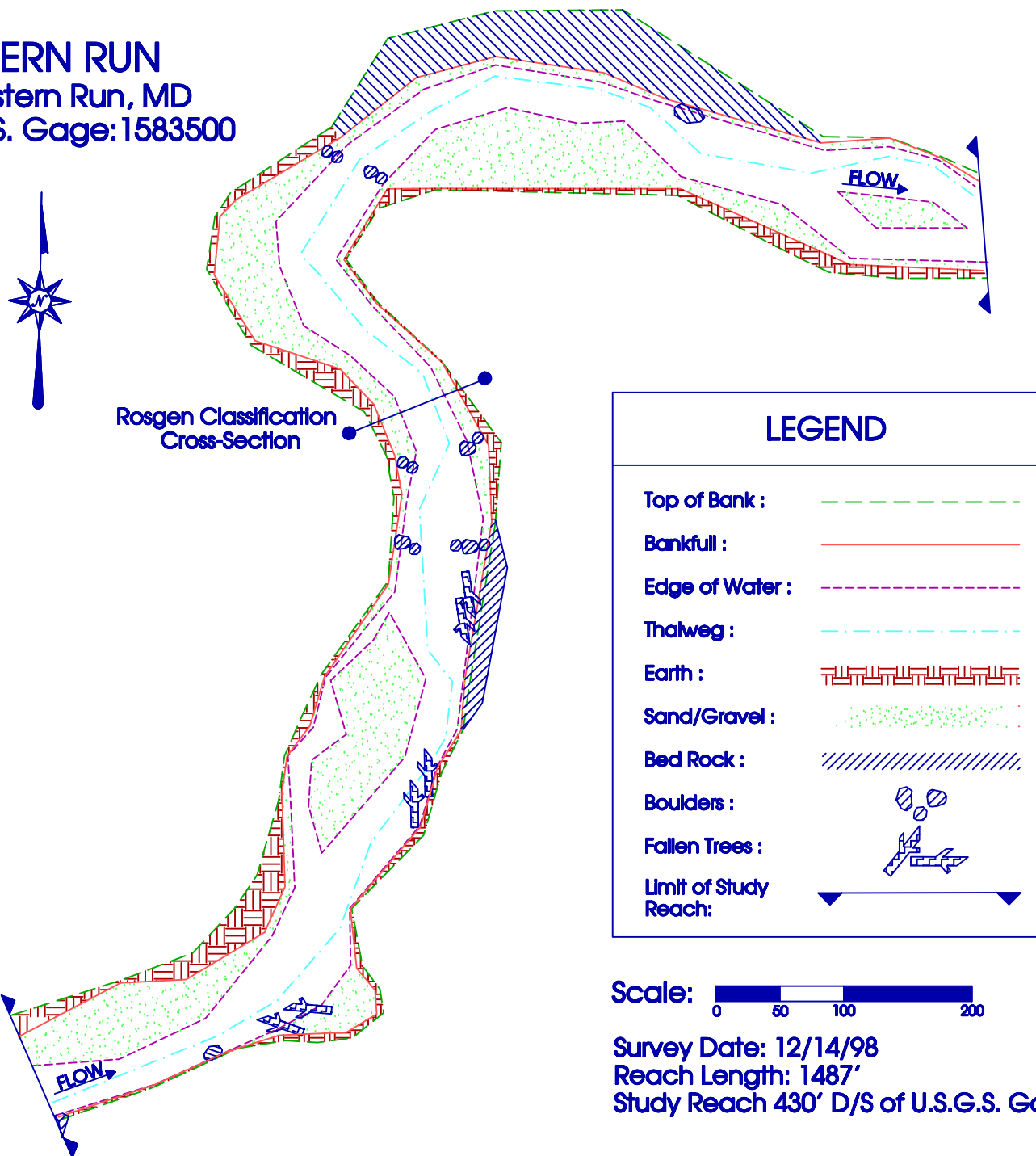
WINTERS RUN NEAR BENSON, MD
USGS STATION NUMBER: 1581700

Latitude:	39° 31' 12"	Gage Period of Record:	1967 - Present
Longitude:	76° 22' 24"	Mean Annual Discharge (cfs):	53.00
ADC Map Coordinates:	Harford / 1992	Rosgen Stream Type:	C4/1
	Map 17 / A-B11	Survey Date:	Sept. 1997
Drainage Area (sq. mi.):	34.80		
Stream Order / Magnitude:	3 / 32		
Percent Imperviousness:	7.55		

Land Use (%): Residential: 21.18   Agricultural: 47.62   Forest: 28.10   Commercial: 2.16

Log-Pearson Flood Frequency Discharge (cfs): $Q_{1.005}$: 293.10 $Q_{1.5}$: 1700.00 $Q_{2.0}$: 2487.50
(Log-Pearson Period: 1967 - 1995)

General Study Reach Description: The downstream end of the study reach is 400 feet upstream of the gage. The reach has pool/riffle features, a straight meander pattern (controlled at one point by gabion revetment) with mid-channel and side bar depositional features, and some lateral scour. There is no large woody debris in the reach. The bank vegetation is a mix of golf course fairway grass and willow/box elder thickets, with a short section of trees, predominately sycamore, red maple and alder, at the downstream end

DISCHARGE BASED ON SURVEY OF GEOMORPHIC FEATURES

Bankfull Discharge (Q_{bkf} cfs):	1961.00	Q_{bkf} / $Q_{2.0}$:	0.79	
Bankfull Return Interval (R.I.):	1.65	$Q_{Top\ of\ Bank}$(cfs):	n/a	R.I.: n/a
Gage Height (ft):	5.95	$Q_{Active\ Channel}$ (cfs):	n/a	R.I.: n/a
Q_{bkf} / $Q_{1.5}$:	1.15			

STUDY REACH SURVEY INFORMATION

Average Water Surface Slope (ft/ft):	0.0052	Flood-prone Width (ft):	250.00
Manning's "n":	0.042	Entrenchment Ratio:	3.73
Mean Bankfull Velocity (ft/sec):	6.64	Width/Depth Ratio:	15.19
u/u*:	7.90	Channel Sinuosity:	1.14
R/D_{84}:	11.68	Beltwidth:	237
Froude Number:	0.56	Meander Width Ratio:	3.5

WINTERS RUN NEAR BENSON, MD
PARTICLE SIZE DISTRIBUTION
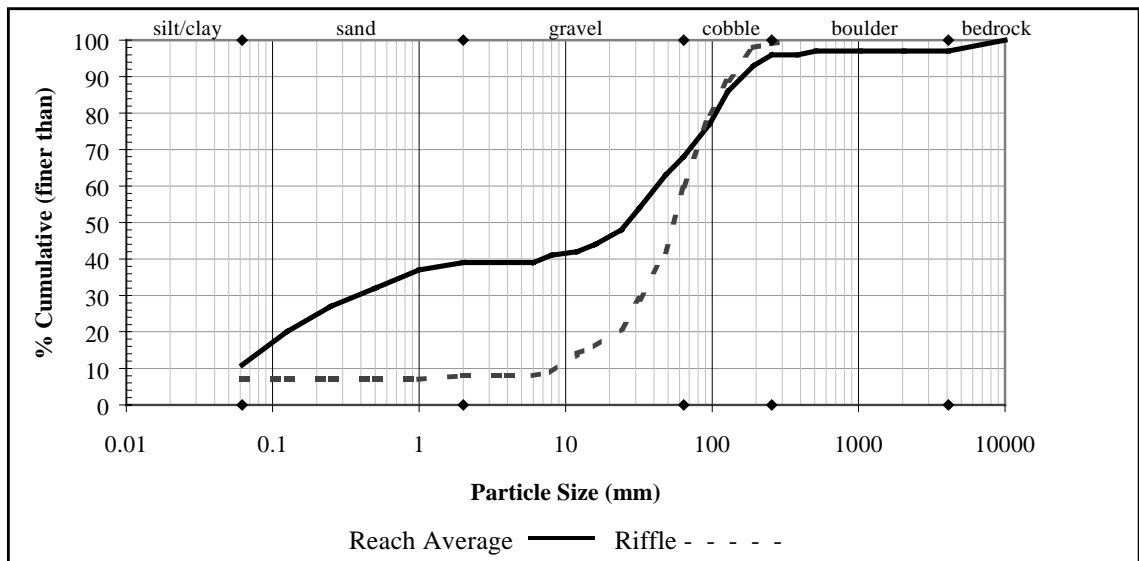
Particle Size (mm)		
Finer Than	Reach	Riffle
D 16	0.09	16.47
D 35	0.76	38.67
D 50	26.42	54.55
D 84	120.07	109.43
D 95	232.59	169.25

STUDY REACH CROSS SECTION
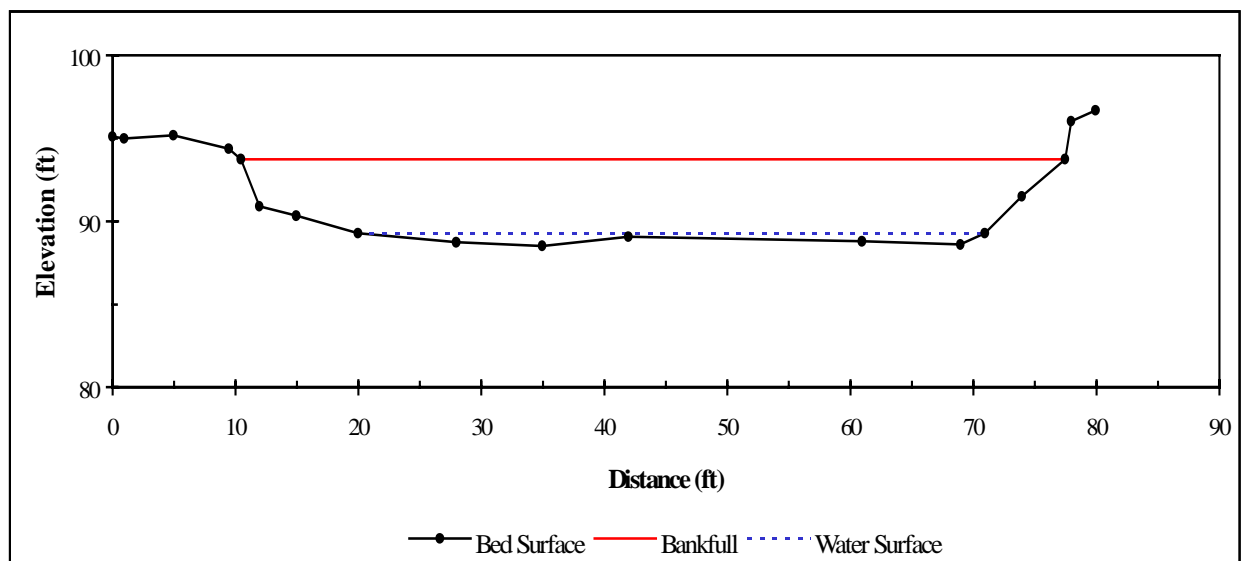
Bankfull Width (ft):	67.00	Mean Bankfull Depth (ft):	4.41
Bankfull Cross-sectional Area (ft^2):	295.54	Maximum Bankfull Depth (ft):	5.24
Hydraulic Radius (ft):	4.20	Wetted Perimeter (ft):	70.45

Winters Run at Benson, Maryland

Downstream view of classification cross-section

Left bank of classification cross-section

WINTERS RUN
near Benson, MD
U.S.G.S. Gage:1581700

FLOW

Gabion Basket Revetment

Golf Cart Bridge

Entrance of Tributary

FLOW

Rosgen Classification Cross-Section

LEGEND

Top of Bank :	– – – –
Bankfull :	————
Edge of Water :	– – – –
Thalweg :	–·–·–
Earth :	▨▨▨
Sand/Gravel :	░░░
Limit of Study Reach:	▼———▼

Scale (ft):

0   50   100   200

Survey Date: 11/20/98
Study Reach Length: 1598'
Study Reach 400' U/S of U.S.G.S. Gage
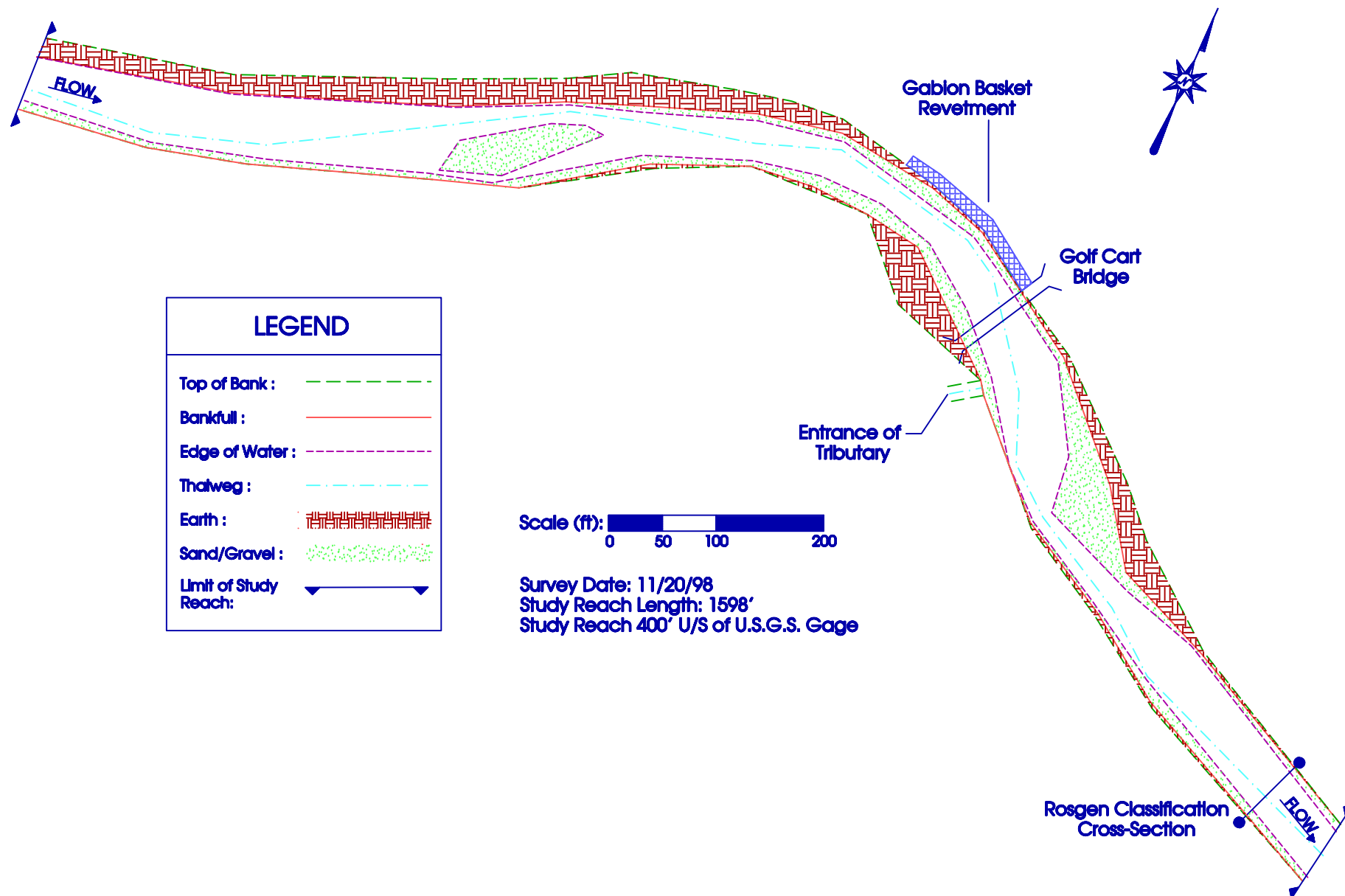
APPENDIX B

PROTOCOLS FOR FIELD SURVEYS AT GAGE STATIONS

Table of Contents

I. INTRODUCTION

The U.S. Fish and Wildlife Service (Service) and Maryland State Highway Administration (SHA) entered into a cooperative agreement to develop regional curves showing bankfull dimensions versus drainage areas for physiographic provinces in Maryland. The short-term goal of the agreement was to develop appropriate relationships of stream characteristics on a statewide basis. The long term goal is to provide the SHA with the information needed to develop improved hydraulic designs of culverts and small bridges which will minimize disturbances to stream channels and their associated flood plains and wetlands.

This document is the procedural protocol to conduct the field data collection. It is divided into two main sections: 1) reconnaissance survey and 2) full field survey. The purpose of the reconnaissance survey is to evaluate and select gage stations for the full field survey. The purpose of the full field survey is to collect all the field data necessary to develop the regional curves and classify the channel using the Rosgen Stream Classification System. Sample field data sheets for all data are provided in Section VI. Field Data Sheets.

II. METHODOLOGY

The methods and procedures presented within this protocol are drawn from several sources, including:

- Annable, W. K., 1994. Morphologic relationships of rural water courses in Southwestern Ontario and selected field methods in fluvial geomorphology. Credit Valley Conservation Authority, Meadowvale, Ontario, Canada.
- Harrelson, C. C., C. L. Rawlins, and J. P. Potyondy. 1994. Stream channel reference sites: an illustrated guide to field technique. Gen. Tech. Rep. RM-245. Fort Collins, CO; U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.
- Leopold, L. B. 1994. A view of the river. Harvard University Press, Cambridge, Massachusetts.
- Rosgen, D. L. 1996. Applied river morphology. Wildland Hydrology, Pagosa Springs, Colorado.

III. RECONNAISSANCE SURVEY

A. **Acquisition of Gage Data**

1. Identify the available gage stations on streams with at least ten years of record and unregulated flow in the geographic area of interest. Locations, identifying names, and gage numbers can be found in the U.S. Geological Survey Water-Data Reports published for each state.
2. Contact the central state office of the Geological Survey and, for each gaging station of interest, request copies of the following:
    *   Gage Description and Station Analysis (including any maps and sketches),
    *   Form 9-207 (the record of discharge measurements),
    *   current or most recent Rating Table,
    *   log-Pearson Type III Flood Frequency Distribution (for the annual maximum series),
    *   peak discharges above base, and
    *   the most recent Level Notes.

B. **Preliminary Analyses**

1. Review Gage Description, Station Analysis, and Level Notes for each station. Gage descriptions should provide bench mark, reference marks, or reference point information in gage datum (if not, contact USGS for relevant datums). Note any unusual information regarding the channel (channelization, stage for weir control, discharge augmentations, etc.).
2. The Gage Description should contain directions to the gage. If not, plot the location of each gage from the latitude and longitude given in the published record, or otherwise determine the location.
3. For each gaging station, plot the Log-Pearson Type III (WRC) flood frequency distribution on log-log paper from the plotting positions provided by the USGS. If the USGS provides exceedence probabilities, convert these to return intervals by calculating the reciprocal. Also, plot the 95% confidence interval for the WRC estimates.
4. Determine the land-use characteristics of the drainage basins for selected gage sites using the MD-SHA's GIS HYDRO program (or if unavailable, use aerial photos). GIS HYDRO is a geographic information system structured for hydrologic analysis that allows users to quickly assemble land use, soil, and slope data for watersheds and then run the SCS-TR-20 hydrologic model for existing and proposed watershed conditions. SHA staff delineate the study watersheds on 7.5 minute USGS topographic maps, and use the GIS HYDRO program to determine the proportion of each basin represented by the characteristics listed below:

- Urban
  - Low density residential
  - Medium density residential
  - High density residential
  - Commercial
  - Industrial
  - Institutional
  - Extractive
  - Open urban
- Agriculture
  - Cropland
  - Pasture
  - Orchards
  - Feeding operations
  - Row crop
- Forest
  - Deciduous
  - Evergreen
  - Mixed
  - Brush
- Open water
- Wetlands
- Barren land
  - Beaches
  - Exposed rock
  - Bare ground

Based on these characteristics, SHA provides an estimate of the percent imperviousness for each watershed, and produce peak run-off estimates (2, 5, 10, 25, 50, and 100 year recurrence intervals) for existing conditions using TR-20 modeling capabilities and USGS regression equations contained in the GIS Hydro program.

C. Initial Gage Reconnaissance

1. The equipment list includes:
   - laser level, laser receiver, and rod,
   - 100 meter or 300-foot tape,
   - colored plastic ribbon and wire flags,
   - field data sheets and pencils,
   - topographic quadrangle maps and aerial photography (if available)of the area,
   - bank pins and cam line,
   - gage description, station analysis, level notes, and plotted data for each gage.
2. Minimum criteria for gage station inclusion:
   - Intact staff plate or recoverable benchmarks referenced to gage datum.
   - Condition and function of the artificial control not affecting medium and high stages.
   - Unarmored channel capable of adjusting to the flow regime. Natural bedrock vertical and horizontal controls are acceptable.
   - Sufficient length (10 – 20 bankfull widths) of channel for a longitudinal profile survey through the gage location.
   - Ten years of record from gage.
3. At the gage site, locate and verify reference marks described in the gage station description. The Level Notes provided by the USGS record the most recent surveyed

gage datum elevation for the reference points, and often contain more precise information on the location of the references.

4. Use the gage key (if available from USGS) to open the gage house or gage box, and read the water surface elevation in gage datum on the water level recorder. Also read and record the gage-datum water-surface elevation on the outside staff gage, and time of reading.

5. Identify a study reach upstream and/or downstream of the gage site. If the stream channel in the vicinity of the gage has been altered appreciably, it may be necessary to extend the survey to include a sufficient length for the study reach The selection of a study reach should consider but not be limited to the following (after Leopold, 1994):

   - The stream should reside within a homogeneous large-scale geologic unit. That is, within the study reach the geology, which influences the channel, should be consistent. For example, a stream meandering in a compacted till would be a homogeneous geologic reach whereas a river passing from a compacted silty till to an outwash sand plain has more than one dominant geologic unit which should be avoided.
   - The topographic relief longitudinal and orthogonal to the channel should remain generally consistent throughout the study reach.
   - The same channel morphology (Rosgen Classification stream type) should be present through the entire study reach.
   - Regions with hydraulic controls such as waterfalls, weirs, bridges, culverts, check dams etc. should be avoided as part of the study reach. Possible exceptions to this criterion might include structures over deeply entrenched (Rosgen Classification A- or F-type) streams where the structure completely spans the channel bed and its banks.
   - Bank and valley vegetation should remain consistent throughout the study reach.
   - The channel length should be no less than two full meander wave lengths (four riffles and four pools) for alluvial type channels and seven to eight successive step-pool series for step pool channels. This equates to a channel length that is approximately 20 times the bankfull width. Exceptions made be made where gage stations are limited and the stream type changes over less than 20 bankfull widths (but should be at least ten bankfull widths).
   - The reach should begin and end on the same type of morphologic feature, i. e., if the reach begins at the top of a riffle, it should end at the top of a riffle.
     Avoid sites with evident impacts (active lateral adjustment, downcutting or aggrading, channelized streams) and fully document any factors on or near the site that influence stream character. It will often be necessary to locate the study reach at some distance from the gage, to minimize the effects of road crossings or other artificial hydraulic features. At the same time, the study reach must be close enough to the gage that significant increases in bankfull discharge are not introduced. Typically, study reaches should be within 20 - 40 widths of the gage. In no case should there be a major tributary confluence between the gage and the study reach. Small tributaries may be present within the reach if the basic parameters of cross-sectional area, bed and bank material composition, and slope do not change upstream or downstream of the confluence.

6. Preliminary Bankfull Calibration
   - Walk the gage and study reaches, and flag several bankfull indicators (consult Section V for guidance on identifying bankfull indicators).
   - Measure the vertical distance between the indicator and water surface. A consistent set of indicators with the same or nearly the same distance above water surface should be apparent. In some locations a lower and upper set of indicators may appear.
   - To find the gage datum associated with a particular set of features, use the vertical distance between the indicator and water surface, and add to the water surface at the gage station to obtain the gage datum or survey the set of indicators through the gage station location using laser level or total station survey. If the gage and study reaches are similar channel types, these bankfull stage estimates should be similar in the two reaches.
   - Using the gage datum, determine the corresponding discharge on the rating table (stage-discharge) provided by the USGS. Determine the recurrence interval for this discharge with the plot of the Log-Pearson Type III flood frequency distribution.
   - If other geomorphic features are identified at different elevations, determine the discharge and recurrence interval for each feature. As a preliminary, and rough, check on the reasonableness of these features, compare them to the discharge predicted by the graph of bankfull discharge versus drainage area for the Eastern United States *(FIGURE 1 – REGIONAL CURVES)* (Dunne and Leopold, 1978).
   - Measure cross-sectional area to determine if the estimated discharge is reasonable for the give cross-sectional area.

Bankfull dimensions vs. drainage areas for various hydro-physiographic provinces

San Francisco Bay region 30" annual precipitation
Eastern United States
Upper Green River, WY
Upper Salmon River, ID

(from Dunne and Leopold, 1978)

Preliminary regression equations developed by USFWS for the Piedmont physiographic province:

Cross-sectional Area - (ft ^{2}) = 17.42 DA $^{0.73}$
Depth - (ft) = 14.78 DA $^{0.39}$
Width - (ft) = 1.18 DA $^{0.34}$

FIGURE 1 – REGIONAL CURVES

B-8

IV. FULL FIELD SURVEY

A. Survey Procedures

Conduct a survey to collect data for a longitudinal profile through the gage and study reach, a Rosgen Stream Type Classification cross-section in the study reach, and additional reach average cross-sections.

1. Longitudinal Profile

This survey will document the overall and facet slopes of the bed, water surface, bankfull, and top of bank along the stream. The longitudinal profile of the study reach is used to calculate the following parameters:

- Stream length: the longitudinal distance along the thalweg of the stream from the beginning to the end of the study reach.
- Stream gradient: the net change in water-surface elevation over the entire study reach divided by the stream length - measured from the same location on the same type of feature. (i.e. top of riffle to top of riffle).
- Riffle length: the thalweg distance between the top and bottom of a riffle.
- Riffle gradient: the change in elevation from the top to the bottom of the riffle divided by the length of the riffle.
- Riffle interval: the longitudinal distance between the beginning of successive riffles. Measured along the thalweg of the channel.
- Inter-step length: the longitudinal distance between the tops of successive steps, measured along the centerline of the channel.
- Step height: the change in elevation between the top and toe of a step.
- Inter-step gradient: the change in elevation between successive steps divided by the inter-step length.
- Maximum pool depth: the maximum depth, measured from the bed to the bankfull elevation, in a pool.

2. Rosgen Stream Type Classification Cross-Section
Survey one cross-section in each study reach to provide the cross-section data (bankfull width and depth, cross-sectional area, and floodprone width) needed to classify the reach according to Rosgen Classification System (Rosgen, 1996). Locate classification cross-sections across the middle of riffles and runs or at the top of steps where the distribution in velocity is considered the most uniform *(FIGURE 2 - CROSS-SECTION LOCATION)*. Establish the classification cross-section perpendicular to the direction of flow, and extending laterally beyond the bankfull channel to one foot above the floodprone elevation. Before measuring the cross-section, install and label rebar monuments for the cross-section. The monuments should be included in the survey and be located sufficiently back from the top of the bank to prevent them from being lost due to bank erosion.
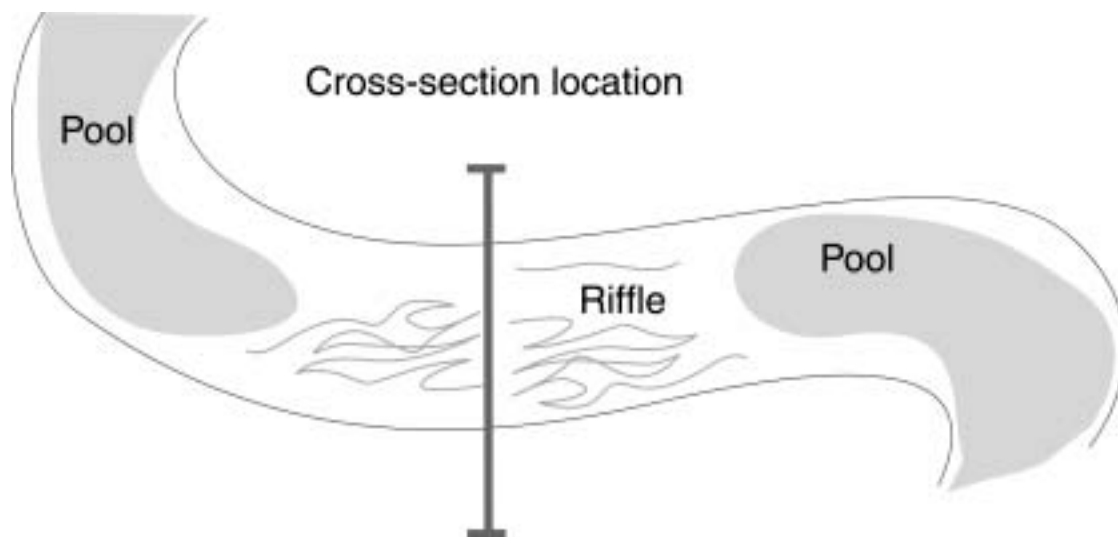
FIGURE 2 – CROSS-SECTION LOCATION

3. Reach Average Cross-sections

Survey, as time permits, additional cross-sections throughout the entire study reach to obtain the average morphological characteristics of the stream in the study reach. Identify reach average cross-section locations during the study reach walk. At a minimum, survey one additional cross-section across the midpoint of a meander bend or at the maximum. depth of the pool. Survey additional cross-sections at mid-riffle or -run, at transitions between riffles and pools and at points of significant change in channel width and slope. The additional cross-sections should include data points at top of bank, bankfull, water surface, toe of bank, and thalweg. For channels with non-uniform bottoms, additional measurements may be required at points of significant slope change, and at enough intermediate points to adequately represent the cross-section. Do not monument these cross-sections with rebar.

B. Survey Setup

1. Refer to the notes from the reconnaissance visit for an estimate of bankfull stage (gage datum). Determine the difference in stage between the bankfull estimate and water surface (be sure to account for differences in water surface from reconnaisance visit and current stage).
2. Walk the entire reach to flag bankfull elevations and other features at tops and bottoms of riffles and runs and other additional locations along the channel with clear bankfull field indicators. Use a laser level or a level line to assist in identifying bankfull field indicators. Also, flag points of maximum pool depths, classification cross-section, and reach average cross-sections. If surveying morphological features in the field, also flag radius of curvature points and the outside bank apexes of meander bends. Use different colored flags to distinguish the longitudinal profile, classification cross-section, and reach average cross-sections from one another.

3. At locations selected for classification cross-sections, install rebar monuments at appropriate distances back from the top of bank on both sides of the stream. Mark these monuments with pin flags and flagging.

4. Also at classification cross-sections, determine the maximum bankfull depth. Then find the points of elevation on both sides of the valley corresponding to a height above the thalweg equal to twice the maximum bankfull depth. These points mark the endpoints of the floodprone width. Mark them prominently with pin flags.

5. Set up the total station or laser level in a location where the benchmarks or reference marks, gage staff plate, and several potential bankfull field indicators can be surveyed. The best location will be that which provides stable footing for the instrument, minimizes the rod extensions, and covers the greatest stream length. Consider setting up in the stream channel if visibility is limited and if the depth and bottom conditions make this feasible (the stream bottom should be stable and the level must not get wet). Having to move the instrument often adds time and complexity to the survey; take the time to select instrument positions carefully.

6. If the study reach does not include the gage, rebar monuments should be installed as reference marks for the survey. The monuments need to be surveyed and elevations and locations obtained in gage datum.

C. Field Data Collection – this may be a laser level survey or a full total station survey. The following description is for total station surveys.

1. Start the survey at one end of the study reach. Determine the ground elevation of the first station relative to the gage datum to begin the survey of the study reach.

2. Once the total station is set there should be one person operating the total station and one or two people with rods and prisms surveying the study reach. The team leader sketches a profile of each bank at all facet features. The sketches include all surveyed points and their elevations. Survey all points for the longitudinal profile, classification cross-section and reach average cross-sections in a sequential pattern, zigzagging back and forth across the stream. Additional points may have to be taken to accurately show the planform of the stream.

3. Maintain close communication between rod-holders and total station operators via two-way radios. Rod-holders will inform the operator of the specific points being surveyed for each shot. Code all data points surveyed according to the total station code card, which all members of the survey team will carry. Rod-holders should inform the total station operator of beginning and end points of linked data sets (i.e., bankfull, thalweg, and water surface). In addition, the team leader will carry a field book noting distance and elevation at facet stations, and describe the bankfull indicator. The team leader will also make notes at the cross-section location on distance, elevation, and describe the bankfull indicator and other geomorphic features, vegetation line, type of vegetation, etc.

4. For the longitudinal profile, survey the points corresponding to top-of-bank (lowest bank), bankfull, active channel, water surface, and thalweg at changes in facet features (i. e., tops and bottoms of riffles) and at the maximum depth locations of pools *(FIGURE 3 – LONGITUDINAL PROFILE)*.
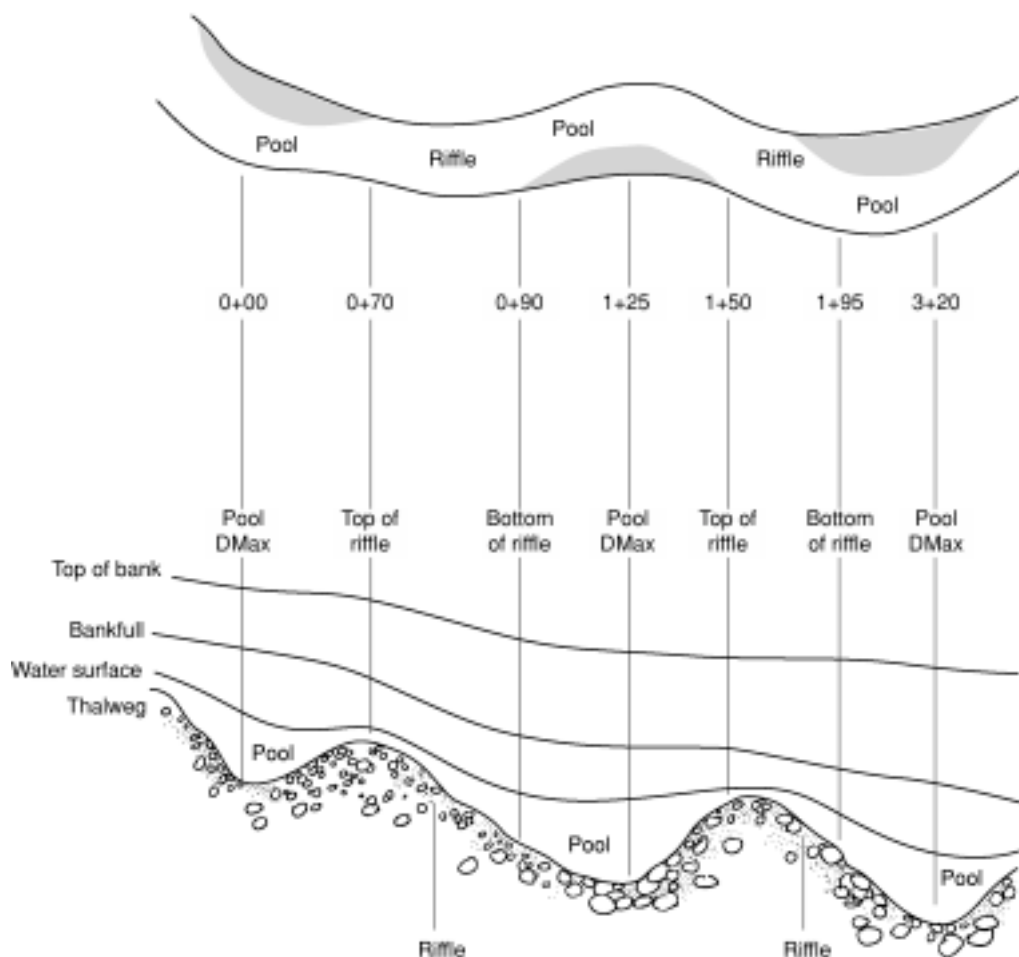
FIGURE 3 – LONGITUDINAL PROFILE

5. On the cross-section survey, note the elevations for the following features *(FIGURE 4 – CROSS-SECTION COLLECTION)*:

- Top and ground surface at monuments
- Slope breaks
- Bankfull stage
- Water surface at the edge of water
- Thalweg

Also survey several points across the floodplain between, and including, the flood-prone elevation points.

B-12
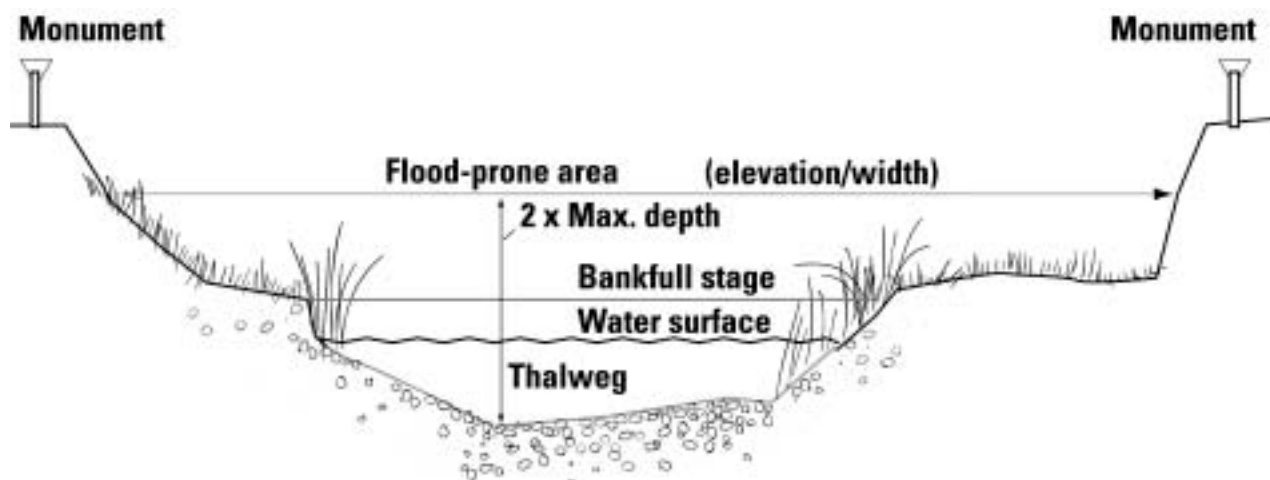
FIGURE 4 – CROSS-SECTION COLLECTION

6. Take photos upstream, downstream, and both banks; include the entire channel cross-section with a vertical survey rod in the frame. If possible, show a survey team member standing at the bankfull elevation. Use a wide-angle lens to show the relative extent of floodplain or confinement on both sides of the channel. Record the camera, lens focal length, frame number and film type on the photo data sheet.

D. Bed and Bank Material Characterization

The work at each study reach includes a basic characterization of bed and bank material, using a combination of pebble counts and bulk samples. Specifically, characterize bed material through the use of a reach average pebble count and a riffle pebble count The collection of bank material data will involve a semi-quantitative description of the bank characteristics and bulk samples.

1. Stream Bed

    Use the Wolman Pebble Count procedure to conduct one reach-averaged and one riffle pebble count. This procedure requires an observer with a metric ruler or calipers that wades the stream and a note-taker. The reach-averaged pebble count characterizes the size distribution of the bed materials comprising the total perimeter of the bankfull channel. The riffle pebble count characterizes the size distribution of particles making up the bed of the riffle, and is used to determine the relative roughness of the channel (mean depth of flow divided by a representative diameter of the bed particles).

    a. *Reach-averaged Pebble Count Procedure*

        Conduct a reach averaged pebble count of 100 samples as follows:

        1. Determine the proportion of the lineal reach represented by major channel unit types (riffle, pool, run/glide, step, etc.).

2. Distribute ten transects through the entire reach according to the proportion of channel features. For example, if 30% of the reach length is in pools, and 70% is in riffles, then locate three transects in pools and seven transects in riffles *(FIGURE 5 – PEBBLE COUNT LOCATION)*. If there are more individual features than needed for the number of transects, locate the transects in features by numbering the units and using a random number table to select those specific features to be sampled. Locate the transects within features by measuring the length of the feature, and use a random number table to select at which distance into the feature the transect is positioned.
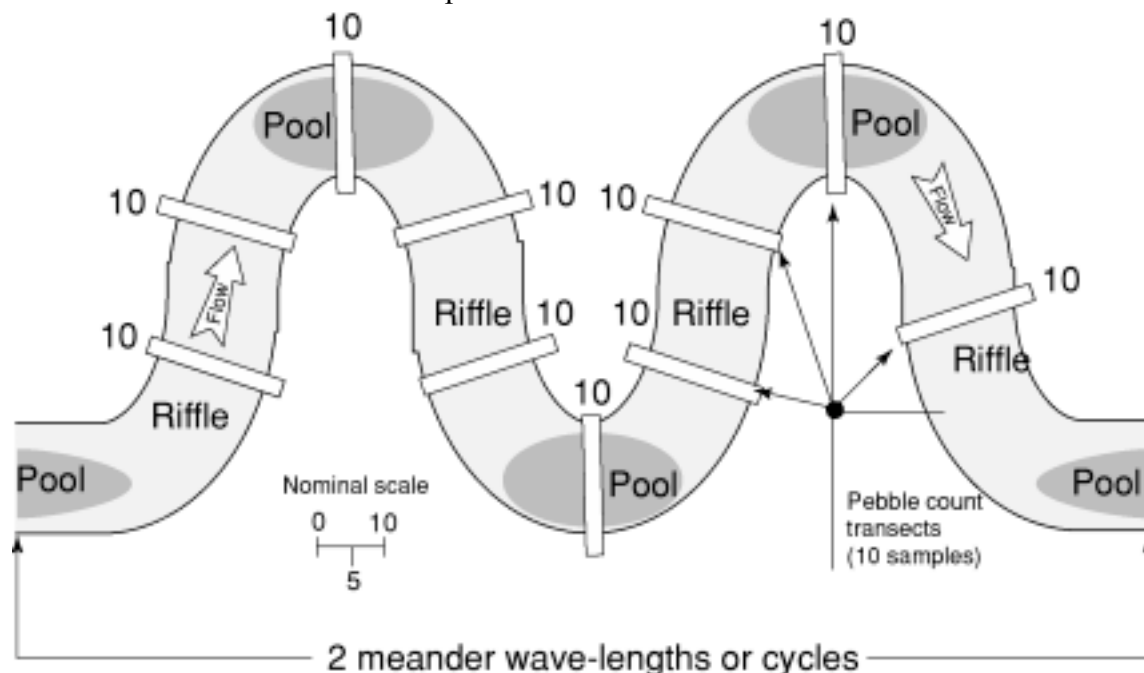
(From Wildland Hydrology, 1998, The Reference Reach Field Book)

FIGURE 5 - PEBBLE COUNT LOCATION

3. Position a taut tape measure across the channel and determine the bankfull width. Divide the distance by nine to determine the interval distance between sample locations. Select the first particle at the zero point of the tape, and the tenth particle at bankfull on the opposite bank. Select the remaining particles at the sampling interval locations along the tape. Avert gaze, and reach straight down at each sampling point along the tape, pick up the first particle touched by the tip of index finger. If the first particle encountered is a sand grain or smaller and is part of a thin sprinkling of particles on the top of a larger particle of gravel, cobble, or boulder, measure the larger particle. If the smaller particles constitute a discrete layer on top of the larger particles, measure the smaller particles.
4. Measure the intermediate axis (neither the longest nor shortest of the three mutually perpendicular sides of each particle picked up). Measure embedded particles or those too large to be moved in place. For these, measure the smaller of the two exposed axes. Call out the measurement. The note taker tallies each

sampled particle by size class and repeats the measurement back for confirmation. A Reach-Averaged Pebble Count Data Sheet is in Section VI – Field Data Sheets. For sand and silt, determine the size class of particles at sample points by visual and textural comparison using the Sand-gauge (available from W. F. McCollough, Beltsville, MD). Classify material as clay when a wet sample readily forms a cohesive ribbon when rolled between fingers or palms. Count the number of particles measured for each transect, there should be ten.

5. Move to the next transect position and repeat the procedure. After ten transects, the sample size should total 100 particles.

b. Riffle Pebble Count Procedure

For streams with riffles, conduct a pebble count at one riffle. If the classification cross-section is located at a riffle, that should be the location for the riffle pebble count.

1. Determine the length of the riffle.
2. Divide the length of the riffle by nine to determine the interval distance between transect locations. Position the first and tenth transects at the start and end of the riffle, respectively, and the other eight transects at the calculated intervals.
3. Measure the sampled particles as in the reach averaged pebble count procedure described above.
4. Record the data on the Riffle Pebble Count Data Sheet (Section VI – Field Data Sheets). On the data sheet, denote bed samples with a dot and bank samples with a slash.

2. <u>Stream Bank</u>

To a limited extent, the reach-average pebble count data characterizes the composition of the material making up the stream banks because the transects for these counts span the complete bankfull channel. However, because measurement includes only a few samples from the bank in the region between the toe and bankfull elevations, conduct additional description of this area as follows:

a. *Sample Procedure*

1) At the classification cross-section, note the type and extent of vegetation covering the banks.
2) Sketch the bank profile for both banks on the bank characterization data sheet. Include the position, thickness, and general composition (i. e., silt, sand, small gravel, gravel/cobble, etc.) of any layering of materials between the toe and bankfull elevations.
3) If vegetation is present, use a square blade spade to scrape a fresh face down the entire bank height.
4) From both right and left banks, collect equal volume bulk samples from the center of each identified layer. The sample size depends on the particle sizes in the identified layers. If bank materials are predominantly larger than gravel, do

not collect a sample; simply describe the general size class as small cobble, large boulder, etc.

5) Record all bank data on the Bank Sample Data Sheet in Section VI – Field Data Sheets.

6) Bag and label the samples separately. Complete the sample sheets and put it in the sample bag. Label the sample bag with stream name, type of sample (i.e., left bank lower stratum), and date.

b) *Dry Sieving for Particle-size Analysis*

1. Upon return to the office, transfer bulk sediment samples from collection bags to pre-weighed drying trays. Make sure the sample tag is transferred with the sediment sample. Allow the sample to air dry for at least 48 hours (stirring at least twice) or until well dried.

2. Pick all visible organic material (leaves, sticks, wood chips, etc.) out of sample.

3. During the drying period, carefully break up the sample using fingers or rubber stopper until it is fine grained and contains no clumps.

4. Calculate, for the left and right bank separately, the proportion of each bank material horizon. Both the left and right banks should each have a sub-sample of 100 grams. Example: If the #1 horizon on the left bank is 2 feet thick and the entire left bank is 8 feet in elevation, then horizon #1 represents 20% of the left bank. Therefore, horizon #1 sample is represented by 20 grams of material. Extract the correct amount by taking blind scoops of each horizon sample until the correct weight is obtained. Place each horizon sub-sample in a pre-weighed container and again make certain that the sub-samples are sufficiently broken down using fingers or a rubber stopper, ensuring no clumps exist.

5. Combine the left and right bank horizon sub-samples into one pre-weighed container. The total sample should now be 200 grams. Weigh the conglomerate and record the data on the Dry Weight Sieve Analysis Data Sheet found in Section VI.

6. If possible, use calipers to measure the intermediate axis (neither the largest or smallest) of largest particle in the composite sample. Use this measurement to select either the 8-inch or 12-inch diameter sieves for sieving the bank sample. If the largest particle in the sample is larger than 16 mm, use the 12-inch diameter sieves. Manually shake until particles have been sieved down to a particle size of less than 16 mm.

7. Once the sample size has a largest particle size of less than 16 mm, use the 8-inch diameter sieves for particle sieving. The first sieve in the nested stack should have a screen size larger than the measurement obtained from the largest particle in the sample. Arrange the sieves in descending order by screen size using no more than five sieves at one time. Place a sieve pan on the bottom and add the dry sample to the top sieve.

8. Place a Ro-Tap lid (mechanical sieve shaker) on the top sieve, load the nested stack into the Ro-Tap machine, and shake the sample for 7.5 minutes. Remove the lid; gently brush each sieve with a nylon brush in descending order. Replace the Ro-Tap lid and shake for another 7.5 minutes.

9. Empty the contents of each sieve into a pre-weighed pan; tap the sieve gently and brush with a nylon brush. Weigh the sample and enter the weights in the "pan" and "pan + sediment" columns of the data sheet (sample in Section VI – Field Data Sheets).
10. Transfer the remaining sediment, if any, from the bottom sieve pan to a temporary container. Arrange the next smallest sieves in descending order with a sieve pan at the bottom. Add the remaining sediment from the temporary container to the top sieve. Repeat steps 8 and 9 until no sediment reaches the sieve pan or the smallest sieve (.062 mm) is used. If the smallest sieve is used and there is still sediment in the sieve pan, weigh the sediment and record it as silt/clay particle size.
11. Subtract the "pan" weight from the "pan + sediment" weight to determine the weight of sediment in each size class, and enter this data in the "sediment" column of the dry sieve data sheet.
12. Sum the sediment weights, subtract the sum from the bulk sample weight to determine the weight of sediment lost, and enter this in the data sheet.

E. Planometric and Meander Geometry Characteristics

The following stream characteristics were obtained from field surveys and/or aerial photographs:

- Meander length - The meander length is the axial distance of one complete sinusoidal wave pattern of the river. For example, if the measurement starts at the midpoint of a bend, the distance of one wavelength is the straight-line distance to the midpoint of the second bend upstream or downstream from the starting point.
- Sinuosity - The ratio of the stream channel length to the valley length. Alternatively, calculate sinuosity as the ratio of valley slope to average stream slope.
- Belt Width - The belt width is the horizontal distance, measured perpendicular to the axis of the valley length and from bankfull to bankfull, which encompasses the limits of the bends of the stream. Where several different belt widths are present in a stream reach, measure all to determine the maximum, average, and minimum values. The Rosgen Stream Classification uses the larger value.
- Meander Width Ratio - This is the ratio of the meander belt width to the bankfull width.
- Radius of Curvature - The constant radius of an arc described around a meander bend. In the field, radii will be measured using one of the following methods:
  * The cord and median distance method for the centerline of the stream ($R_c = C^2 / 8M$ where C is the length of a straight line between two points along the curve and M is the distance from the midpoint of C to the curve). An alternative way to measure radius of curvature is to use the cord and median distance method for the bankfull on the outside of a meander. The equation for that method is $R_c = C^2 / 8M + M/2$.
  * Where site conditions permit, direct measurement via the two-tape method. Two survey team members position themselves in the centerline of the stream at the entrance and exit of the bend. Pull tape measures from each person to a counterpoint equidistant from both, and note the distance. Measure the distance

from the counterpoint to the centerline of the stream at the bend apex. Estimate the radius of curvature as the average of the three measured radii.
* A total station survey of the bend for planform geometry.

V. DETERMINATION OF BANKFULL STAGE

Bankfull discharge largely controls the form of alluvial channels. In many cases, bankfull discharge closely corresponds to the effective discharge or to the flow that transports the largest amount of sediment over the long-term under current climatic conditions. This may also be the channel maintaining flow. Bankfull discharge is that discharge of stream water that just begins to overflow into the active floodplain. The active floodplain is defined as a flat area adjacent to the channel constructed by the river and overflowed by the river at a recurrence interval of about 2 years or less. Erosion, sediment transport, and bar building by deposition are most active at discharges near bankfull. The effectiveness of higher flows, called overbank or flood flows, does not increase proportionally to their volume above bankfull, because overflow into the floodplain distributes the energy of the stream over a greater area.

If you observe the stream at bankfull discharge, the water level will be obvious, but this discharge is infrequent. The average discharge, which you are more likely to encounter, fills about 1/3 of the channel, and is reached or exceeded only 25% of the time. Finding indicators of bankfull stage (or elevation) in order to calculate stream discharge is crucial, but this may be difficult in the field. Stream-types and indicators vary, and the process requires many separate judgments; a lack of consistency by a single person or among several people can yield poor results.

The active floodplain is the flat, depositional surface adjacent to many stream channels. It is the best indicator of bankfull stage. Floodplains are most prominent along low-gradient, meandering reaches (e.g., Rosgen Classification type C and E channel). They are often hard or impossible to identify along steeper mountain streams (Rosgen Classification types A and B). They may be intermittent on alternate sides of meander bends or may be completely absent. Steep, confined streams in rocky canyons often lack distinguishable floodplains, so other features must be used. Recently disturbed systems may give false indications of bankfull.

Where floodplains are absent or poorly defined, other indicators may serve as surrogates to identify bankfull stage. The importance of specific indicators varies with stream type. Several indicators should be used to support identification of the bankfull stage; use as many as can be found. Useful indicators include:

- Top of Point Bars. The point bar consists of channel material deposited on the inside of meander bends. They are a prominent feature of Rosgen C type channels but may be absent in other types. Record the top elevation of point bars as the lowest possible bankfull stage since this is the location where the floodplain is being constructed by deposition.
- Change in Vegetation. Look for the low limit of upland, perennial vegetation on the bank, or a sharp break in the density or type of vegetation. On surfaces lower than the floodplain, vegetation is either absent or annual. During a series of dry years, such as 1985-1990 in much of the western United States, perennial plants may invade the formerly active floodplain. Large

magnitude floods may likewise alter vegetation patterns. On the floodplain (above bankfull stage) vegetation may be perennial but is generally limited to typical streamside types. Willow, alder, or dogwood often form lines near bankfull stage. The lower limit of mosses or lichens on rocks or banks, or a break from mosses to other plants, may help identify bankfull stage.

- Change in Slope. Changes in slope occur often along the cross-section (e.g., from vertical to sloping, from sloping to vertical, or from vertical or sloping to flat at the floodplain level). The change from a vertical bank to a horizontal surface is the best identifier of the floodplain and bankfull stage, especially in low-gradient meandering streams. Many banks have multiple breaks; examine banks at several sections of the selected reach for comparison. Slope breaks also mark the extent of stream terraces, which may be measured and mapped in your survey. Terraces are old floodplains that have been abandoned by a downcutting stream. They will generally have perennial vegetation, definite soil structure, and other features to distinguish them from the active floodplain. Most streams have three distinct terraces at approximately 2 to 4 feet, 7 to 10 feet, and 20 to 30 feet above the present stream. Avoid confusing the level of the lowest terrace with that of the floodplain; they may be close in elevation.

- Change in Bank Materials. Any clear change in particle size may indicate the operation of different processes (e.g., coarse, scoured gravel moving as bedload in the active channel giving way to fine sand or silt deposited by overflow). Look for breaks from coarse, scoured, water-transported particles to a finer matrix that may exhibit some soil structure or movement. Changes in slope may also be associated with a change in particle size. Change need not necessarily be from coarse to fine material but may be from fine to coarse.

- Bank Undercuts. Look for bank sections where the perennial vegetation forms a dense root mat. Feel up beneath the root mat and estimate the upper extent of the undercut. (A pin-flag may be inserted horizontally and located by touch at the upper extent of the undercut as a datum for the rod.) This is usually slightly below bankfull stage. Bank undercuts are best used as indicators in steep channels lacking floodplains. Where a floodplain exists, the surface of the floodplain is a better indicator of bankfull stage than undercut banks that may also exist.

- Stain Lines. Look for frequent-inundation water lines on rocks. These may be marked by sediment or lichen. Stain lines are often left by lower, more frequent flows, so bankfull is at or above the highest stain line.

Deposits of pine needles, twigs, and other floating materials are common along streams, but they are seldom indicators of bankfull stage. A receding stream may leave several parallel deposits. Floods may also leave organic drift above bankfull stage.

If stream gage data is available for the stream, observations of indicators at or near the gages may help to identify the indicators most useful for a particular area. Ratios of present to bankfull discharge can be used to estimate bankfull stage at nearby sites. Bankfull discharges tend to have similar flow-frequency (approximately 1.5 years) and flow-duration characteristics among sites in a given climatic region. Use this ratio and observations of bankfull stage at local stream gages to test the reliability of the various indicators for your geographic area. Compare your calculation of bankfull discharge to the regional averages by drainage area. If it is different, refer to the USGS peak flow procedures for the area to determine if a significantly different area-runoff relationship exists. In the absence of other reasonable explanations, examine your methods.

Marking Indicators of Bankfull Stage
The field determination of bankfull stage is basically detective work. Crew members walk the selected reach and mark probable indicators (using pin flags, flagging tied on shrubs, etc.). This usually involves discussion and even some disagreement as to the significance of individual marks. Wade the center of the channel to view bankfull stage along both banks. During the process, visualize the water surface at bankfull and note channel features such as bars, boulders, and rootwads that may affect water surface elevation or direct the current. The final test of bankfull indicators is measuring their elevation as part of the survey and plotting a longitudinal profile of bankfull elevation for the entire reach. A line drawn through the points represents the sloping plane of bankfull flow. Significant scatter of bankfull elevations is normal. Outlying points will be evident and may be rechecked to see what sort of indicator gives the most useful and consistent results for the selected reach.

VI. FIELD DATA SHEETS (Follow)

- Longitudinal Profile
- Cross-Section
- Reach Average Pebble Count
- Riffle Pebble Count and Largest Particle on Bar
- Cross-Section Bank Characterization
- Dry Weight Sieve Analysis

STREAM:							DATE:			CREW:				
USGS #			ALL MEASUREMENTS IN FEET UNLESS OTHERWISE NOTED.											
FWS #			REFERENCE POINT ELEVATION AND DESCRIPTION:											
Identifier	Backsight	Height of Instrument	Station	Bed Surface Foresight	Bed Surface Elevation	Water Surface Foresight	Water Surface Elevation	Bankfull Foresight	Bankfull Elevation	Top of Bank Foresight	Top of Bank Elevation	Other Foresight	Other Elevation

MARYLAND STREAM STUDY

CROSS SECTION

STREAM	DATE
USGS #	CREW
FWS #	

Begin on left, facing downstream (all measurements are in feet unless otherwise noted)

NOTE	DIST.	ELEV. / DEPTH	NOTE	DIST.	ELEV. / DEPTH	STATION OR DISTANCE FROM GAGE
						DIRECTION FROM GAGE
						NOTATIONS
						NOTE · **ABBREV**
						Left · **L**
						Right · **R**
						Pin · **P**
						Edge of Water · **EW**
						Water Surface · **WS**
						Active Channel · **AC**
						Scour Line · **SL**
						Bankfull · **BF**
						Top of Bank · **TOB**
						Monument · **MON**
						ENTRENCHMENT
						FLOODPRONE WIDTH
						BANKFULL WIDTH
						ENTRENCHMENT
						GPS Coordinates
						Left Monument
						Latitude
						Longitude
						Error
						Right Monument
						Latitude
						Longitude
						Error
						Instrument (Prop.#)

MARYLAND STREAM STUDY
REACH AVERAGE PEBBLE COUNT

STREAM				DATE	
USGS #				CREW	
FWS #				PARTICLE TALLY COUNTS BY TRANSECT	

FEET	PARTICLE	MILLIMETERS		1	2	3	4	5	6	7	8	9	10	TOT#	ITEM%	%CUM
	Silt/Clay	< .062	S/C													
	Very Fine	.062 - .125	S													
	Fine	.125 - .25	A													
	Medium	.25 - .50	N													
	Coarse	.50 - 1.0	D													
	Vry Coarse	1.0 - 2	S													
	Very Fine	2 - 4														
	Fine	4 - 6	G													
	Fine	6 - 8	R													
	Medium	8 - 12	A													
	Medium	12 - 16	V													
	Coarse	16 - 24	E													
	Coarse	24 - 32	L													
	Vry Coarse	32 - 48	S													
	Vry Coarse	48 - 64														
0.21-0.31	Small	64 - 96	C													
0.31-0.42	Small	96 - 128	O													
0.42-0.63	Large	128 - 192	B													
0.63-0.84	Large	192 - 256	L													
0.84-1.26	Small	256 - 384	B													
1.26-1.68	Small	384 - 512	L													
1.68-3.36	Medium	512 - 1024	D													
3.36-6.72	Lrg	1024 - 2048	R													
6.72-13.43	Vry Lrg	2048-4096														
	Bedrock	>4096	BDRK													
CHANNEL WIDTH AT TRANSECT																

	LENGTH				TRANSECT	FEATURE	LENGTH	LOCATION	COUNT
REACH		PROPORTION	NO. UNITS	SAMPLED	1				
POOL					2				
RIFFLE					3				
RUN					4				
					5				
					6				
					7				
					8				
					9				
					10				

]

MARYLAND STREAM STUDY
RIFFLE PEBBLE COUNT AND LARGEST PARTICLE ON BAR COUNT

STREAM		DATE	
USGS #		CREW	
FWS #		RIFFLE LOCATION (ALSO MARK ON REACH SKETCH):	

			PARTICLE TALLY COUNTS BY TRANSECT										TOTALS	
FEET	PARTICLE	MILLIMETERS	1	2	3	4	5	6	7	8	9	10	Tot #	% Cum
	Silt/Clay	< .062	S/C											
	Very Fine	.062 - .125	S											
	Fine	.125 - .25	A											
	Medium	.25 - .50	N											
	Coarse	.50 - 1.0	D											
	Vry Coarse	1.0 - 2	S											
	Very Fine	2 - 4												
	Fine	4 - 6	G											
	Fine	6 - 8	R											
	Medium	8 - 12	A											
	Medium	12 - 16	V											
	Coarse	16 - 24	E											
	Coarse	24 - 32	L											
	Vry Coarse	32 - 48	S											
	Vry Coarse	48 - 64												
0.21-0.31	Small	64 - 96	C											
0.31-0.42	Small	96 - 128	O											
0.42-0.63	Large	128 - 192	B											
0.63-0.84	Large	192 - 256	L											
0.84-1.26	Small	256 - 384	B											
1.26-1.68	Small	384 - 512	L											
1.68-3.36	Medium	512 - 1024	D											
3.36-6.72	Lrg	1024 - 2048	R											
6.72-13.43	Vry Lrg	2048-4096												
	Bedrock	>4096	BDRK											
	CHANNEL WIDTH AT TRANSECT													

LARGEST PARTICLES ON BAR

BAR LOCATION (ALSO MARK ON REACH SKETCH):													
Bar Length:	Part. #	A mm	B mm	C mm	Part. #	A mm	B mm	C mm	Part. #	A mm	B mm	C mm	
Bar Width (Thalweg - Bnkfl):	1				9				17				
Sketch bar profile (thalweg - bnkfl)	2				10				18				
	3				11				19				
	4				12				20				
	5				13				21				
	6				14				22				
	7				15				23				
	8				16				24				

STREAM	DATE
USGS #	CREW
FWS #	

Begin on left, facing downstream (all measurements are in feet unless otherwise noted)

NOTE	DIST.	ELEV. / DEPTH	NOTE	DIST.	ELEV. / DEPTH	STATION OR DISTANCE FROM GAGE
						DIRECTION FROM GAGE
						NOTATIONS
						NOTE — **ABBREV**
						Left — **L**
						Right — **R**
						Pin — **P**
						Edge of Water — **EW**
						Water Surface — **WS**
						Active Channel — **AC**
						Scour Line — **SL**
						Bankfull — **BF**
						Top of Bank — **TOB**
						Monument — **MON**
						ENTRENCHMENT
						FLOODPRONE WIDTH
						BANKFULL WIDTH
						ENTRENCHMENT
						GPS Coordinates
						Left Monument
						Latitude
						Longitude
						Error
						Right Monument
						Latitude
						Longitude
						Error
						Instrument (Prop.#)

DRY WEIGHT SIEVE ANALYSIS

Stream:				Sample Type:		Pavement	Subpavement		Bank		Bar

USGS #:			Location:

FWS#:

Date:	**PRE-SIEVE BULK WEIGHT**	
Collected By:	**"PAN + SEDIMENT"**	
Sieved By:	**"PAN"**	
	"SEDIMENT"	

INCHES	PARTICLE	MILLIMETERS		"PAN"	"PAN + SEDIMENT"	"SEDIMENT"	ITEM%	%CUM
	Silt/Clay	< .062	S/C					
	Very Fine	.062 - .125	S					
	Fine	.125 - .25	A					
	Medium	.25 - .50	N					
	Coarse	.50 - 1.0	D					
	Vry Coarse	1.0 - 2	S					
.08 - .16	Very Fine	2 - 4	G					
.16 - .31	Fine	4 - 8	R					
.31 - .63	Medium	8 - 16	A					
.63 - 1.26	Coarse	16 - 32	V					
1.26 - 2.5	Vry Coarse	32 - 64	L					
Sum of "Sediment" Weights:								
% LOSS = (BULK WT SEDIMENT - SUM SEDIMENT WTS)/BULK WT SEDIMENT X 100 =								